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A COMPUTER FALLOUT MODEL USING VARIABLE

WINDS FOR OPERATIONAL TYPE STUDIES
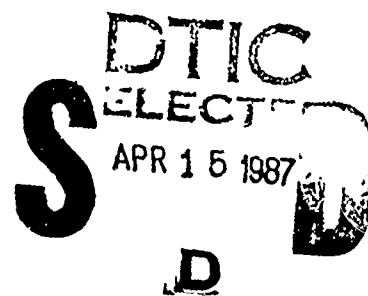
THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Nuclear Engineering

Anthony B. Strines, Jr., B.S.

Captain, USAF

March 1987

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INSPECTED
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Preface

The purpose of this thesis project was to develop and document a fast, simple, fallout smear code which uses real winds to give realistic dose rate contour patterns on the ground. The wind fields are modeled using spectral coefficients derived by the National Meteorological Center. The code was evaluated by comparing its output against the output of REDRAM, another variable wind code which was the first fallout code to use spectral coefficients.

The Engineering Survivability Branch of the Aeronautical Systems Division aided in this project by providing the spectral coefficients for code testing and evaluation. In particular, I am grateful to Lt. Jeff Brown for his assistance in this area.

Special thanks go to Dr. Charles J. Bridgman, my thesis adviser, for his constructive guidance throughout this project.

Last but not least, I thank my wife Betsy, who has supported me throughout my tour at AFIT.

<div align="right">Tony Strines, Jr.</div>

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Abstract

A radioactive fallout code, HYDRA, has been developed that uses real winds to determine dose rate contours on the ground. These winds are calculated from spectral coefficients derived by the National Meteorological Center. HYDRA models the radioactive dust cloud as a set of pancake clouds, each cloud representing a different particle size group. Each particle size group is transported to the ground through a discretely layered atmosphere using McDonald-Davies fall mechanics. Dose rate contours are determined by smearing the cloud activity along the ground as the cloud descends.

HYDRA was evaluated against another variable wind fallout code, REDRAM. HYDRA's multiple pancake cloud model, as compared to the single pancake cloud model used in REDRAM, produced the same contour patterns for yields between 10 and 2000 kilotons. Outside this range, however, dose rates along the hotline were lower and the contours wider for HYDRA's multiple pancake cloud model.

The Colarco coefficients used in REDRAM were found to consistently underestimate particle size. Variations were as high as six percent for yields ranging from 100 to 1000 kilotons. HYDRA did not use Colarco's approximation.

HYDRA successfully produced dose rate contours at nine global locations.

A COMPUTER FALLOUT MODEL USING VARIABLE WINDS FOR OPERATIONAL TYPE STUDIES

I. Introduction

Radioactive Cloud Formation and Fallout

When a nuclear weapon is detonated, a tremendous amount of energy is released, mostly as X-ray photons. The weapon material and casing are initially subjected to temperatures as high as ten million degrees Kelvin and are totally vaporized (10:27). The X-ray energy is completely absorbed by the surrounding air at distances ranging from ten to several hundred meters from the weapon, creating a spherical fireball that initially has a temperature of several thousand degrees Kelvin (3).

Because the fireball is hotter and less dense than the surrounding air, a large pressure differential exists between the two regions. This creates a strong updraft leading into the fireball. If the burst is close enough to the earth's surface, large amounts of dirt and dust are sucked by the updraft up into the fireball and are vaporized along with the weapon material. The fireball also starts to rise due to its lower density. (10:35)

As the fireball rises, it expands and cools by radiating energy and by mixing with the surrounding air. The dirt, dust, and weapon debris condense to form a radioactive dust cloud that has now become toroidal in shape due to the updrafts (See Fig. I-1) (10:28). The cloud is made
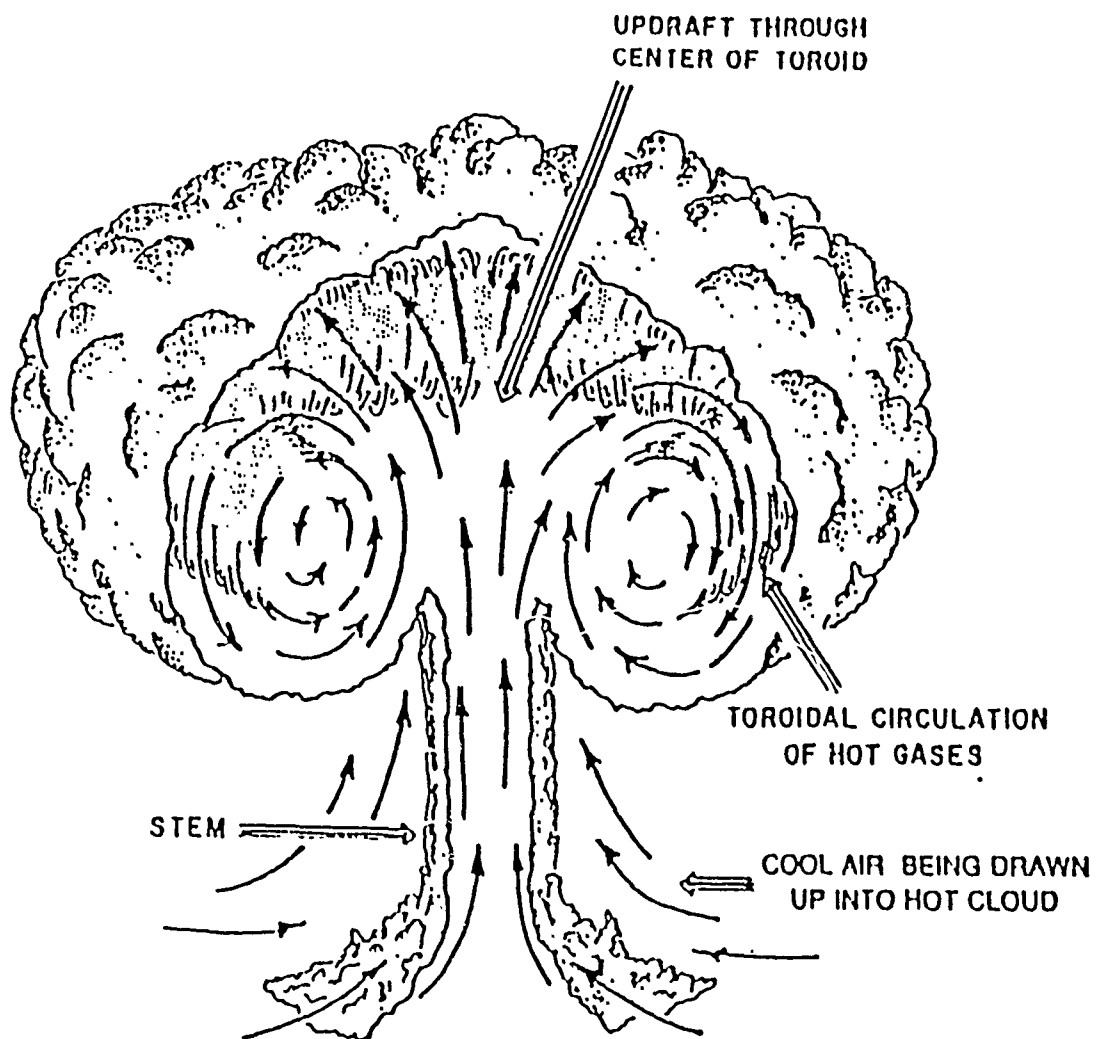
Fig. I-1. Toroidal Circulation in a
Radioactive Dust Cloud (10:29)

up of particles which contain radioactive fission products both within their volumes and on their surfaces (4). Eventually, after approximately ten minutes or so, the cloud cools to the same temperature as the surrounding air, and is said to be "stabilized" (10:32). At this point, the cloud stops rising, although it will continue to spread in the horizontal direction (10:32). For megaton bursts, the cloud does not stabilize until it has reached the stratosphere.

Under the influence of gravity, the radioactive particles carried aloft and formed in the cloud fall to the ground at rates determined by the particle size (7,10). Where the particles land is also determined by particle size and by the local winds. The deposition of these particles on the ground is known as "fallout".

The amount and location of radioactive fallout are of critical importance to military and civilian personnel involved in disaster preparedness or other similar programs. Computer codes which predict fallout have existed since the late 1950's (12:3). Two basic categories of fallout models exist today: numerical disk tossers and smearing models (14:5).

The numerical codes model the cloud formation and particle deposition processes in much greater detail than the smearing codes do and are able to handle variable wind fields as well (22). However, they are complex codes that require large amounts of computer time, and thus are not

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suitable for studies where multiple runs of the code are necessary (23:1).

The smearing codes use empirical formulas based on fallout data from nuclear weapons tests (12:2). They are simple and fast, but cannot handle variable winds, assuming instead a constant wind in one direction at all altitudes. This is a critical restriction which greatly limits the accuracy of these models (5:208). Even so, smearing codes are the codes of choice for large studies because of their fast run times. Hopkins developed a smearing code which treated variable winds using spectral coefficients (29). Hopkins' code proved to be fast and accurate (15), but the code was developed for research, is not documented, and is not in a form which makes it easy to use.

Problem Statement

The goal of this thesis was to develop and document a fast, simple, fallout smear code that uses real wind fields to transport the fallout particles to the ground and gives a realistic curved hotline. Hopkins' method of spectral coefficients is used to model the wind fields. The code is intended for use in fallout studies at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Scope

The computer code developed in this thesis, named HYDRA (for Hotline Yield-Dependent Residual Activity), is limited to the following scenario:

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1. Only one weapon can be detonated at any given time.

2. The weapon is detonated on the earth's surface. Air bursts or underground bursts cannot be modeled using this code.

3. Only local fallout is modeled. Local fallout is defined as fallout which reaches the ground in 24 hours or less.

4. Particle transport is accomplished by gravity and the local winds.

5. Dose rate contours are calculated only on the earth's surface. No attempt is made to calculate the activity in the air as the cloud descends to the earth.

Assumptions

HYDRA assumes the following:

1. The fallout particles are spherical in shape. Thus, McDonald-Davies fall mechanics can be used to model particle fall.

2. Particles do not begin falling out of the cloud until after the cloud has stabilized.

3. The local winds change gradually over distance.

4. There is no wind component in the vertical direction.

5. All radioactivity is taken into the cloud. There is no stem fallout.

6. There is no washout of the particles from precipitation.

General Approach

The general approach taken in determining the fallout contours consists of four basic steps. First, the radioactive cloud is divided into a number of particle size groups that is specified by the code user. The average height to

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which each particle size group is injected is then deter-
mined by empirical formulas derived by Hopkins from numeric
code data (14:14).

Once the particle injection heights have been calculat-
ed, each particle size group is transported to the ground
through an atmosphere that has been divided into ten lay-
ers, with the center of the top layer being the particle
injection height for that particle size. Davies-McDonald
fall mechanics (7,19) are used to determine the length of
time it takes each particle group to reach the ground.
Spectral coefficients are used to calculate the wind fields
in each atmospheric layer and transport the particle groups
to the ground. Connecting the ground coordinates for each
particle group yields the curved hotline, the line along
which the dose rate will be a maximum for a given distance
from the burst location.

Once the hotline has been located, points off the hot-
line are found for user-specified dose rates using the same
empirical formulas found in the smearing codes.

In the final step, the hotline points and dose rate
points are plotted on maps to give dose rate contours any-
where in the world. DISSPLA software is used for this pur-
pose. The program which takes the data points and plots
them is named HYDMAP.

User's Guides

The development of user's guides for HYDRA and its
associated codes was an integral part of this project.

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These guides were designed to be used with the CDC Cyber 750 computer using the Network Operating System (version 2.4.2). Three user's guides have been written: one for HYDRA, one for HYDMAP, and one which describes how to create a file containing the spectral coefficients from raw wind data.

Sequence of Presentation

The remainder of this report is divided into the following sections:

1. Section II gives brief descriptions of some of the more well-known numeric and smearing codes.

2. Section III details the program code theory and development.

3. Section IV presents the program evaluation and discussion.

4. Section V presents the conclusions.

5. The user's guides are presented in Appendices D, E, and F.

II. Current Fallout Prediction Models

Numeric Codes

Numeric codes employ numeric integration to determine ground fallout. The radioactive cloud, the atmosphere, and time are divided into cells, with fallout particles being transported to the ground in discrete steps (5:205). The most popular and well-known of the numeric codes is the DEfense Land Fallout Interpretive Code, or DELFIC. DELFIC is intended for use in research and to be a standard of comparison for production (analytic) codes (22:1). It "predicts local fallout from nuclear weapons explosions in the yield range from 0.001 to 100,000 kilotons over a range of heights of burst from shallow subsurface to fallout-safe airbursts" (22). Local fallout is defined in the DELFIC manual as "the intensely radioactive material which falls to the ground within several to several hundred miles of ground zero" (22:7).

In DELFIC, the radioactive cloud is modeled as an "entraining bubble of hot gas" by dynamic equations using atmospheric temperature, pressure, humidity, and wind data (22:7). After the cloud has stabilized, it is divided into several cylindrical shaped clouds, with each cloud consisting of particles of a single size unique to that cloud (22:27). Each of the particle clouds is then further divided in the vertical direction into disks (22:28).

Once the different disks have been identified, each disk is transported to the ground using variable or con-

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stant wind fields. The atmosphere is divided into a discrete number of layers, with each layer subdivided into rectangular cells. The disks are then transported through this layered atmosphere, their horizontal location at any time being determined by the wind vectors associated with each rectangular cell. (27:10)

The rate at which the particles fall to the ground is determined by the particle size. DELFIC assumes all particles are spherical and that the particles obey the Davies fall mechanics equations (27:5). The particle size distribution defaults to a lognormal distribution, but other particle size distributions may be specified (22:15).

Compared to the smearing codes, DELFIC models the physical processes of a nuclear explosion much more realistically and therefore gives more realistic fallout contours. However, as mentioned previously, DELFIC is extremely complex and requires long run times, and therefore is not suited for studies where the code must be run repeatedly. Also, the contour patterns produced by DELFIC have been observed to break up at distances far from ground zero (2).

Smearing Codes (WSEG-10 and AFIT)

Two smearing codes will be reviewed here: 1) the Weapons System Evaluation Group code (WSEG-10), and 2) the Air Force Institute of Technology code (AFIT). Both use empirical formulas derived from nuclear weapons test data (12:3). However, the AFIT code relies less on empirical formulas

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than does WSEG-10. In the AFIT code, empirical relations are used mainly for describing the initial location of the stabilized cloud, while key computations are based on physical relations. These codes are known as "smear" codes because the effect achieved by the dose rate formula used is to smear the radioactive cloud along the ground as it travels downwind (5:208). Smear codes have very fast run times and no contour pattern break-up, but the accuracy may be less than that achieved by the disk tosser codes.

The dose rate formula, the fundamental equation of the smearing codes, is given as (5:207):

$$\dot{D}_1(x,y) = (K)(Y_k)(FF) \int_0^\infty f(x,y,t')g(t')dt' \qquad (II\text{-}1)$$

where $\dot{D}_1(x,y)$ is the unit time reference dose rate in roentgens/hr,

K is the source normalization constant in roentgen-km^2 per hour-kiloton,

Y_k is the weapon yield in kilotons,

FF is the fission fraction (normally taken to be 50%),

$f(x,y,t')$ is the normalized horizontal distribution of the cloud activity per unit area at time t' (units of km^{-2}), and

$g(t')$ is the fraction of the total activity that arrives on the ground per unit time (units of inverse hours).

The term $\dot{D}_1(x,y)$ is an artificial quantity that is the dose rate "at location x and y at one hour if all of the activity which will eventually land at x,y is assumed to be down at one hour" (5:207). The function $f(x,y,t')$ is

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assumed to be Gaussian in both the x and y directions and
is given by the formula (5:207):

$$f(x,y,t') = \frac{1}{\sqrt{2\pi}\ \sigma_x(t')} \ EXP\left[-0.5\left(\frac{x - v_x t'}{\sigma_x(t')}\right)^2\right]$$

$$X \quad \frac{1}{\sqrt{2\pi}\ \sigma_y(t')} \ EXP\left[-0.5\left(\frac{y - v_y t'}{\sigma_y(t')}\right)^2\right] \quad (II-2)$$

where $\sigma_x(t')$ is the standard deviation in kilometers of the
cloud activity in the x direction,

v_x is the x component of the wind velocity in km/hr,

$\sigma_y(t')$ is the standard deviation in kilometers of the
cloud activity in the y direction, and

v_y is the y component of the wind velocity in km/hr.

The source normalization constant is a function of
"the radioactivity produced per kiloton of fission yield,
the energies of the emitted gamma radiation, the properties
of the air, and the self-absorption of the ground" (5:207-
208). Various values for the source normalization constant
have been used over the years, ranging from 2654 to 6990
r-km^2/hr-kt (8:24). Davis has recently calculated a lower
bound of 5729 r-km^2/hr-kt for Nevada Test Site soil (8:23).

WSEG-10. WSEG-10 was first published in 1959 and has
been the most popular smearing fallout prediction code in
use since that time. The code models fallout from nuclear
explosions with yields ranging from 0.001 to 100 megatons,
and is limited to surface bursts. (12:3-5)

WSEG-10 models the radioactive cloud as a Gaussian

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cylinder. The cloud is stabilized and the center of the cloud reaches its maximum height in 15 minutes or less (12:5). The maximum cloud center height is given by the formula (12:6):

$$H_c = 44.0 + 6.1 \ln(Y_m)$$
$$- .205 \; |\ln(Y_m) + 2.42| \; (\ln(Y_m) + 2.42) \qquad \text{(II-3)}$$

where Y_m is the weapon yield in megatons and H_c is the maximum cloud center height in kilofeet.

The $g(t')$ function in WSEG-10 is an empirical fit to weapons test data, and is given by the formula (12:10):

$$g(t') = \frac{(F) \; EXP(t'/T_c)}{(T_c) \; \Gamma(1 + 1/n_o)} \qquad \text{(II-4)}$$

where F is approximately equal to 1.0,
T_c is a time constant, and
$n_o = 1.5 - .25(H_c/60)$. $\qquad$ (II-5)

WSEG-10 assumes a constant wind field such that the wind direction becomes the x direction and the y component of the wind velocity is zero. The $f(x,y,t')$ function then becomes:

$$f(x,y,t') = \frac{1}{\sqrt{2\pi} \; \sigma_x(t')} \; EXP\left[-0.5\left(\frac{x - v_x t'}{\sigma_x(t')}\right)^2\right]$$

$$X \; \frac{1}{\sqrt{2\pi} \cdot \sigma_y(t')} \; EXP\left[-0.5\left(\frac{y}{\sigma_y(t')}\right)^2\right] \qquad \text{(II-6)}$$

If one assumes that the activity is constant over a few

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cloud standard deviations, then $\sigma_{x,y}(t') = \sigma_{x,y}(t_a)$, where t_a is the time of arrival of the cloud center line on the ground for a given particle (4). The $f(x,y,t')$ function can then be split into an $f(x,t')$ function and an $f(y,t_a)$ function, where:

$$f(y,t_a) = \frac{1}{\sqrt{2\pi}\ \sigma_y(t_a)}\ EXP\left[-0.5\left(\frac{y}{\sigma_y(t_a)}\right)^2\right] \quad (II-7)$$

Since $f(y,t_a)$ is no longer dependent on t'', it can be moved outside the integral in Equation II-1, which then becomes:

$$\dot{D}_1(x,y) = (K)(Y_k)(FF)f(y,t_a)\int_0^\infty f(x,t')g(t')dt' \quad (II-8)$$

If it is assumed that the $g(t')$ function is a slowly changing function, then it can be represented in a Taylor expansion about the time of arrival (4). If one changes the lower limit of integration in Equation II-8 from 0 to $-\infty$, the integral may be solved analytically with the solution being (4):

$$\int_{-\infty}^{\infty} f(x,t')g(t')dt' = g(t_a)/v_x$$

Equation II-8 then becomes an analytical expression easily solved in a computer code (14:8):

$$\dot{D}_1(x,y) = \frac{(K)(Y_k)(FF)g(t_a)}{\sqrt{2\pi}\ \sigma_y(t_a)v_x}\ EXP\left[-0.5\left(\frac{y}{\sigma_y(t_a)}\right)^2\right] \quad (II-9)$$

The activity-size distribution for the WSEG-10 model which led to the empirical expression for $g(t)$ was (12:7):

$$A(r) = \frac{1}{\sqrt{2\pi} \; \beta r} \; EXP\left[-.5\left(\frac{\ln(r_m) - \ln(r)}{\beta}\right)^2\right] \qquad (II\text{-}10)$$

where r_m is the median radius (= 44 microns),
  r is the particle radius in microns, and
  β = 0.690.

While fast and simple, WSEG-10 has many limitations which adversely affect its accuracy. These limitations were summarized by Bridgman and Bigelow (5):

1. Restriction to a constant wind field gives poor results if winds are varying.

2. The form of the $g(t')$ function predicts activity on the ground at zero time, which is physically unrealistic.

3. The activity-size distribution assumes all activity is evenly distributed throughout the particle volume. In fact, it is fractionated, with part of the activity distributed in the volume and the rest deposited on the surface.

4. The activity-size distribution predicts too high an activity level downwind by putting too much of the activity in particles with radii of 10 microns or more (the median radius is too large).

5. For low yield weapons, the downwind activity close to ground zero is underestimated because the activity-size distribution is too narrow (β is too small).

6. The particle size cannot be varied (2). This is especially limiting since the $g(t)$ function (as will be shown later) is dependent on the particle size.

AFIT. The AFIT code, developed at the Air Force Institute of Technology also uses Equation II-9, but contains significant improvements which answer criticisms 2-6 listed in the previous section. The improvements were made in the

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activity-size distribution and in the $g(t')$ function.

The AFIT normalized activity-size distribution is actually the combination of two lognormal functions and is given by the formula (5:211):

$$A(r) = \frac{f_v}{\sqrt{2\pi} \; \beta r} \; EXP\left[-.5\left(\frac{\ln(r) - a_3}{\beta}\right)^2\right]$$

$$+ \; \frac{(1-f_v)}{\sqrt{2\pi} \; \beta r} \; EXP\left[-.5\left(\frac{\ln(r) - a_2}{\beta}\right)^2\right] \qquad (II-11)$$

where f_v is the fraction of the activity that is distributed throughout the particle volume,
$a_2 = \ln(r_m) + 2\beta^2$,
$a_3 = \ln(r_m) + 3\beta^2$,
r_m is the median size of the number-size distribution, and
β is the logarithmic slope of the number-size distribution.

In the AFIT $A(r)$ distribution, r_m and β can be varied, whereas in the WSEG-10 code, these values are fixed.

The AFIT $g(t)$ function (dropping the prime) is based on McDonald-Davies fall mechanics (7,10), and is not an empirical fit to weapons test data as is the WSEG-10 $g(t)$ function. Bridgman reasoned that $g(t)$ and $A(r)$ are both particle distribution functions and thus must be related according to the equation (5:210):

$$g(t)dt = A(r)dr$$

$$\text{or} \quad g(t) = A(r)dr/dt \qquad (II-12)$$

where dr/dt is the rate of change in the size of the particles hitting the ground with respect to the time of arri-

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val. If A(r) is known, all one must do is find dr/dt to determine g(t). In one version of the AFIT code, the quantity dr/dt is determined using sets of coefficients published by Colarco (6). These coefficients resulted from an empirical fit to results calculated from the McDonald-Davies fall mechanics equations described in the next chapter. The coefficients are dependent on the particle injection height (6:7). The AFIT g(t) function has a value of zero when the arrival time is zero, thus answering criticism #2 of the previous section.

III. Program Code Theory and Development

Overview

The program developed for this thesis, named HYDRA (Hotline Yield-Dependent Residual Activity), is essentially identical to Hopkin's variable wind code (14). The fallout cloud is divided into a user-specfied number of particle size groups which are gravity-sorted within the cloud, the heavier particles residing in the lower part of the cloud. Each particle size group is then transported separately to the ground through a discretely layered atmosphere using McDonald-Davies fall mechanics (7,19) and real winds. Wind field vectors are determined using the method of spectral coefficients at specified points along a given particle trajectory (14,15).

The connected ground coordinates for each particle size group form the fallout hotline. Along this hotline, the dose rate will be a maximum for any specified distance from the weapon detonation point. The dose rate for any point on or off the hotline is calculated using Equation II-1. Dose rate contours are then overlayed on maps to indicate local fallout for any point on the globe excluding the poles.

The program code theory and program development is divided into the following sections:

1. Particle size selection.

2. Cloud rise modeling.

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3. Particle fall mechanics.

4. Activity-size distribution.

5. Wind vector calculations.

6. Wind shear calculations.

7. Calculation of g(t).

8. Dose rate calculations.

9. Dose rate contour mapping.

Each topic is discussed in one of the following sections.

Particle Size Selection

HYDRA is intended for local fallout studies, where local fallout is the fallout that reaches the ground in 24 hours or less. Having the user choose the particle sizes which all fall within 24 hours may lead to difficulties, since the arrival time for a given particle size depends on the weapon yield. Therefore, a routine was developed that automatically selects the particle sizes once the number of particles has been specified by the user. This routine first finds the radius of the particle that will land in approximately 24 hours (hereafter referred to as the critical radius), and calculates the corresponding value of the cumulative lognormal activity-size distribution (See Fig. III-1). The range between this corresponding value and the highest possible value of 1.0 is then divided into a number of areas equal to the number of particles, with each area being represented by its corresponding particle radius.

The critical radius is found using McDonald-Davies fall mechanics. The particle injection height is deter-

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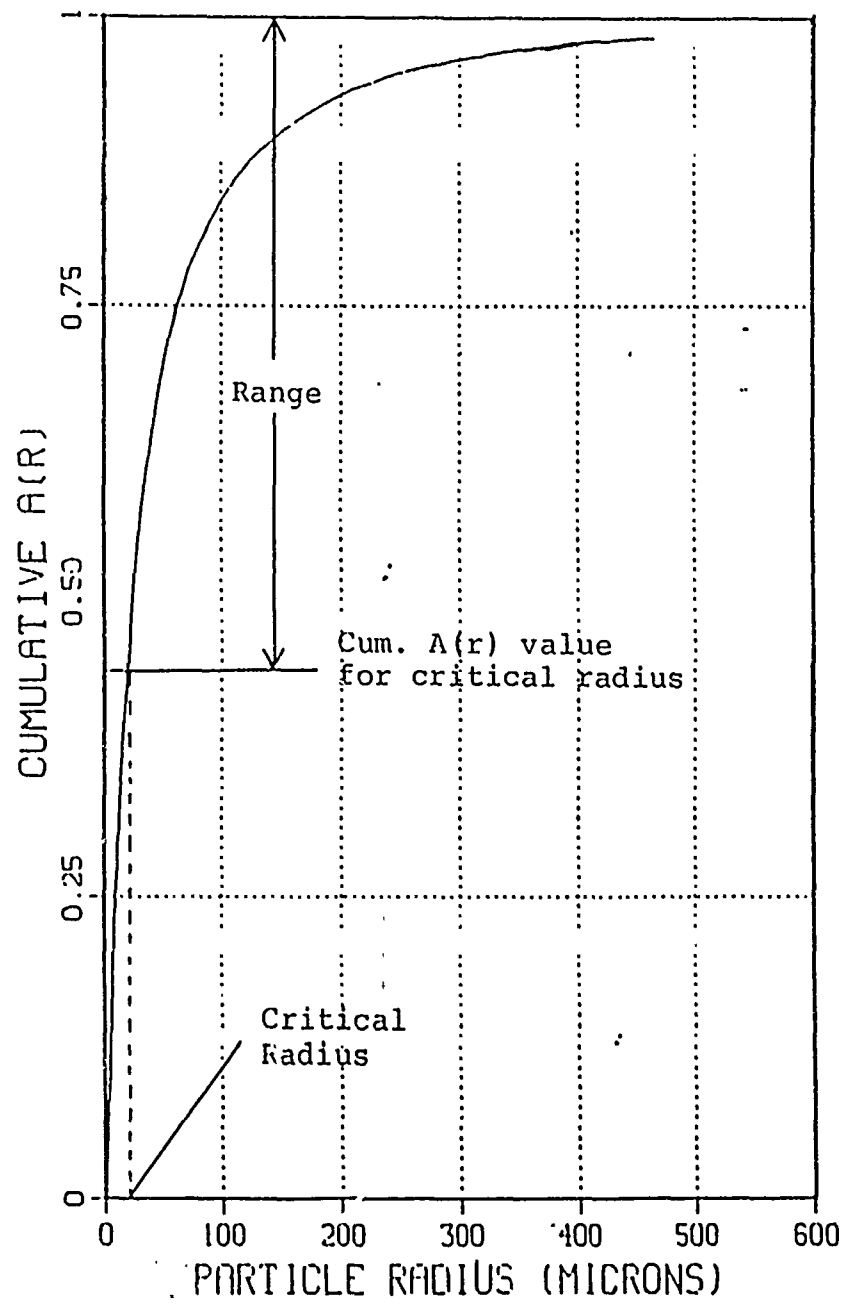
Fig. III-1. Cumulative Activity-Size Distribution

mined using Equation II-3 from WSEG-10. The particle falls
from this height to the ground through a single layered
atmosphere. The average fall velocity for the particle is
assumed to be the velocity calculated at the altitude mid-
way between the injection height and sea level. The time
of arrival to the ground is then simply the injection
height divided by the fall velocity. An initial particle
radius of 5.0 microns is chosen, and its time of arrival is
calculated. The radius of the particle is increased in
increments of 1.0 microns in a simple iterative process
until the arrival time is less than 24 hours. One micron
is then added to the particle radius, and this new particle
radius is the critical radius.

Once the critical radius has been determined, the cor-
responding value of the cumulative activity-size distribu-
tion is calculated. The activity-size distribution used
here is Freiling's approximation of Equation II-11 (4):

$$A(r) = \frac{1}{\sqrt{2\pi} \ \beta r} \ \text{EXP}\left[-.5\left(\frac{\ln(r) - \alpha_{2.5}}{\beta}\right)^2\right] \quad \text{(III-1)}$$

where $\alpha_{2.5} = \ln(r_m) + 2.5 \ \beta^2$. The cumulative $A(r)$ distribu-
tion is then given by (4):

$$\text{Cum. } A(r) = \int_0^r A(r')dr' \quad \text{(III-2)}$$

If the following change of variable is made:

$$x = (\ln(r) - \alpha_{2.5}) \ / \ \beta \quad \text{(III-3)}$$

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then Equation III-2 becomes:

$$\text{Cum. } A(x) = \int_{-\infty}^{x} A(x')dx' \qquad \text{(III-4)}$$

where $A(x)$ is a normal function. Equation III-4 is solved using an IMSL Fortran subroutine to find the cumulative distribution value corresponding to the critical particle.

Once the cumulative distribution value of the critical radius has been determined, the range between this distribution value and the highest possible distribution value (1.0) is divided into equal segments whose number is equivalent to the number of particles. Then, the cumulative function values representing each segment are fed into another IMSL subroutine to find the corresponding particle radii.

Cloud Rise Modeling

The cloud rise model used in HYDRA is similar to the one found in WSEG-10 and the AFIT model. The cloud is assumed to stabilize quickly and particle fallout does not begin until after the cloud has stabilized. However, whereas WSEG-10 and earlier versions of the AFIT code use a single particle injection height for all particle sizes, HYDRA uses a different injection height for each particle size group. Each height represents the center of a wafer cloud consisting of monosized particles (14:11).

Hopkins discovered that using a single injection height for all particle sizes "severely restricts hotline curvature" (14:31), giving a false hotline. His solution

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to the problem was to derive an empirical formula for particle injection heights based on a least squares fit to DELFIC data for yields ranging from 1.0 kilotons to 15.0 megatons (14:11). The formula is (14:14):

$$H_c = (SLOPE)(D_p) + INTERCEPT \qquad (III-5)$$

where H_c is the average height in meters of the wafer center in the stabilized cloud,

D_p is the particle diameter in microns,

$SLOPE = -EXP(1.574 - .01197lnY + .03636(lnY)^2$
$- .0041(lnY)^3 + .0001965(lnY)^4)$

in meters/micrometer,

$INTERCEPT = EXP(7.889 + .341nY + .001226(lnY)^2$
$- .005227(lnY)^3 + .000417(lnY)^4)$

is the altitude in meters for a particle of zero diameter on a linear fit, and

Y is the weapon yield in kilotons.

The particle injection height is determined for each particle in subroutine ARRTIM.

Particle Fall Mechanics

The particle fall mechanics are modeled using the McDonald-Davies equations and a discretely layered atmosphere. All particles are assumed to be spherical. First, the atmosphere is divided into ten layers as in Hopkin's variable wind model. Hopkins found that while the optimum number of layers was 24, using 10 layers resulted in only a 5.0 percent decrease in accuracy while reducing the computer calculation time by a factor of two (24:29). The center

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of the highest layer is the particle injection height, so each particle size has its own set of ten layers. This is different from Hopkins' model, where one set of layers is defined for all particle sizes, with the center of the highest layer being the injection height of the smallest particle.

For the top and bottom of each layer, the air density, dynamic viscosity, and particle fall velocity are calculated. Air density and dynamic viscosity are determined using empirical formulas of the U.S. Standard Atmosphere (21). The McDonald-Davies equations are used to determine the particle fall velocity. The force balance equation for falling particles in air is (19:463):

$$.5 \rho_a v_z^2 C_d \pi r^2 = (4/3)\pi r^3 \rho_f g \qquad \text{(III-6)}$$

where ρ_a is the air density, C_d is the drag coefficient, v_z is the fall velocity, r is the particle radius, and the quantity $.5 \rho_a v_z^2$ is the dynamic pressure. For a given particle size and altitude, there are two unknowns in this equation: v_z and C_d. The Reynolds number for falling spheres is given by (19:463):

$$R = 2v_z \rho_a r/\eta \qquad \text{(III-7)}$$

where η is the dynamic viscosity. Substituting Equation III-7 into Equation III-6 yields the following relationship (5:212):

$$R^2 C_d = 32 \rho_a \rho_f g r^3/(3 \eta^2) \qquad \text{(III-8)}$$

Thus, the quantity R^2C_d can be easily determined for a given particle size and altitude.

Once the quantity R^2C_d is known, the Reynolds number R can be determined using empirical relations developed by Davies (5:212):

$$R = R^2C_d/24 - 2.3363E-04(R^2C_d)^2 + 2.0154E-06(R^2C_d)^3$$
$$- 6.9105E-09(R^2C_d)^4$$
$$\text{for } R^2C_d \leq 100.0, \text{ or}$$
$$\log(R) = -1.29536 + .986\log(R^2C_d) - .046677[\log(R^2C_d)]^2$$
$$+ .0011235[\log(R^2C_d)]^3$$
$$\text{for } R^2C_d > 100.0 \qquad \text{(III-9)}$$

Equation III-7 can then be used to find the fall velocity at a given layer boundary. This value is then corrected for drag slip at high altitudes by multiplying it by a correction factor taken from DELFIC (5:212):

$$CF = 1 + 1.165E-07/r\rho_a \qquad \text{(III-10)}$$

where r is the particle radius in meters and ρ_a is the air density in kg/m3.

The particle fall velocity through a given layer is assumed to be the average of the velocities at the layer boundaries. The time it takes the particle to fall through the layer is then simply the layer thickness divided by the average fall velocity. Summing the individual fall times for each layer gives the time of arrival on the ground for a particle.

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Air density and dynamic viscosity at the layer boundaries are calculated in subroutine STDATM. The fall velocity at the layer boundaries is calculated in subroutine VFALL. Both subroutines are called by subroutine ARRTIM. Average fall velocities, fall times, and the time of arrival are calculated in subroutine ARRTIM.

Activity-Size Distribution

The activity-size distribution used in HYDRA is the same one used in the AFIT code, and is given by Equation II-11. It is calculated in subroutine ACTVTY. The parameters r_m and β are input variables.

The g(t) Function

The g(t) function in HYDRA, as in the AFIT code, is given by the following equation (5:210):

$$g(t) = A(r)dr/dt \qquad (III-11)$$

However, a different method is used to calculate dr/dt.

Where the AFIT code employed the Colarco coefficients to calculate dr/dt, HYDRA uses a finite difference method. First, the given particle size is multiplied by 0.99 and 1.01 to yield two particles sizes which bound the given particle size. Then, the arrival times for these "bounding" particles are calculated using the methods described in the above sections. The value for dr/dt is easily calculated using the formula:

$$dr/dt = ABS\ (R2 - R1)/(T2 - T1) \qquad (III-12)$$

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where R2 = 1.01 X (particle radius),

R1 = 0.99 X (particle radius),

T2 is the arrival time for the particle of radius R2,

and   T1 is the arrival time for the particle of radius R1.

Colarco's coefficients were not used because Bridgman reported deviations of 10 to 13 percent in the arrival times for certain radii when compared to pure fall mechanics theory. (2)

The quantity dr/dt is calculated in the main program of HYDRA. The g(t) function is calculated in subroutine ACTVTY.

Wind Shear Calculations

Wind shear calculations in HYDRA are identical to those in Hopkins' model. Wind shear is the "local variation of the wind vector or any of its components in a given direction" (17:631). For a discretely layered atmosphere, the shear of a wind component in any given layer is the difference in the wind components at the top and bottom of the layer divided by the layer thickness. However, in HYDRA the shear in a given layer is weighted by the residence time of the particle in the layer such that the total shear experienced by a particle can be represented by the formula (15:36):

$$SHRTOT = \left[\sum (SHR^2(i) \times TFALL(i)/TARRIV)\right]^{\frac{1}{2}} \quad (III-13)$$

where SHRTOT is the total root-mean-square shear in the X
        or Y direction,

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SHR(i) is the shear experienced by a particle in the ith layer in the X or Y direction,

TFALL(i) is the residence time of the particle in the ith layer,

TARRIV is the arrival time of the particle on the ground,

and TFALL(i)/TARRIV is the weighting factor for the ith layer.

Wind shear will spread the fallout contour out laterally from the hotline (18:1). All wind shear calculations are performed in the main program of HYDRA.

Variable Wind Calculations

The distance in the X and Y directions that a particle travels as it falls through a given layer is assumed to be the particle fall time for that layer multiplied by the average wind velocity components encountered in the layer. The distances computed for each layer are then summed to find the total horizontal transport experienced by the particle as it falls to the ground.

The wind velocity components may be determined in one of two ways. The first method, employed in DELFIC, uses a three dimensional grid and assigns wind component values to the grid points. Values for locations not on the grid points are linearly interpolated. The second method, used in Hopkins' code and in HYDRA, represents the wind components as the truncated sum of orthogonal functions in spherical coordinates, and is known as a spectral representation. To use this method, the complex coefficients of the

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functions must be determined. (11:214)

The main reason that spectral representation was chosen over the grid method is that an evenly spaced gridded wind mesh fine enough for linear interpolation is not available on a global scale. Spectral representation has an additional advantage in that there is no need to map the globe (1:399).

The complex coefficients are derived from wind data collected at 1415 stations around the northern hemisphere. Balloons with sensors are released at these stations twice a day at midnight and noon Greenwich Mean Time (GMT). The lateral displacement of each balloon is measured at certain altitudes, and from these lateral displacements the wind data is calculated. The wind data is fed into the program AFGL which outputs the complex wind coefficients. AFGL is composed of subroutines taken from a weather forcasting model used at the Air Force Geophysics Laboratory, Hanscom AFB. The complex wind coefficients are contained in the file SPECOEF, which is an input file for HYDRA. These wind coefficients are divided into 12 sets or "spectral layers", one set for each of the 12 altitudes at which the wind velocity is determined (See Fig. III-2). (24:2,3)

The vorticity, divergence, continuity, adiabatic thermodynamic, and hydrostatic equations are the set of equations that describe the adiabatic, frictionless flow of the atmosphere (20:737). The vorticity equation is the curl of the vector equation of motion, while the divergence equa-

KILOMETERS   MILLIBARS

20.6 ┌─────────────────────────────┐   50

18.5 ├─────────────────────────────┤   70

.16.2 ├─────────────────────────────┤   100

13.6 ├─────────────────────────────┤   150

11.8 ├─────────────────────────────┤   200
10.4 ├─────────────────────────────┤   250
9.2 ├─────────────────────────────┤   300

7.2 ├─────────────────────────────┤   400

5.6 ├─────────────────────────────┤   500

3.0 ├─────────────────────────────┤   700

1.5 ├─────────────────────────────┤   850
0.1 └─────────────────────────────┘   1000

ABOVE SEA LEVEL

Fig. III-2.   Spectral Levels of the AFGL Model (24:12)

tion results from taking the divergence of the equation of
motion (17:174,615).

The above equations all contain the velocity in vector
form as a variable. The Helmholtz theorem states that the
horizontal wind vector can be expressed as the sum of irro-
tational and non-divergent fields according to the formula
(20:737):

$$\overline{V} = \overline{V}_\psi + \overline{V}_\chi \qquad \text{(III-14)}$$

with

$$\overline{V}_\psi = \hat{k} \times \nabla\psi \quad ; \quad \overline{V}_\chi = \nabla\chi \qquad \text{(III-15)}$$

where ψ is the stream function,

     χ is the velocity potential,

     $\hat{k}$ is the vertical unit operator, and

     ∇ is the horizontal gradient operator.

The stream function is a scalar function, and for non-
divergent flow is defined such that (17:548):

$$u = -\,\partial\psi/\partial Y \quad ; \quad v = \partial\psi/\partial X \qquad \text{(III-16)}$$

where u is the wind component in the X or longitudinal
direction, and v is the wind component in the Y or latitudi-
nal direction. The velocity potential is also a scalar
function, and for irrotational flow is defined such that
(17:608):

$$u = -\,\partial\chi/\partial X \quad ; \quad v = -\,\partial\chi/\partial Y \qquad \text{(III-17)}$$

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The quantities u and v are the ones needed to compute the horizontal particle transport in HYDRA. However, the attempt to represent these quantities as spectral sums is an awkward exercise which can be avoided if the following substitutions are made (24:8):

$$U = u(\sin\theta) \quad ; \quad V = v(\sin\theta) \qquad (III-18)$$

where θ is the colatitude.

Now, the task is to represent the quantities U and V as sums of the orthogonal functions Y_n^m, where Y_n^m are functions of the longitude λ and colatitude θ. These functions Y_n^m are solutions of the equation (11:215):

$$a^2 \nabla^2 Y_n^m + n(n+1)Y_n^m = 0 \qquad (III-19)$$

where a is the radius of the earth. The Y_n^m functions are of the form (11:215):

$$Y_n^m = EXP(im\lambda) \times P_n^m \qquad (III-20)$$

where P_n^m are polynomials of order m and degree n. Substituting Equation III-20 into Equation III-19 yields (11:215):

$$\frac{d^2 P_n^m}{d\theta^2} + \cot\theta \frac{dP_n^m}{dt} + \left[n(n+1) - \frac{m^2}{\sin^2\theta} \right] P_n^m = 0$$

$$(III-21)$$

where t represents time.

Equation III-21 is a variation of Legendre's equation,

and its solutions P_n^m are associated Legendre polynomials (11:215). The solutions P_n^m, when normalized, are defined as (29:24):

$$P_n^m = \frac{(-1)^{m+n}}{2^n n!} \left[\frac{(2n+1)(n-m)!}{2(n+m)!} \right]^{\frac{1}{2}} (1-x^2)^{m/2}$$

$$X \quad \frac{d^{m+n}}{dx^{m+n}} (1-x^2)^n \qquad (III-22)$$

where $x = \cos\theta$. In HYDRA, the functions P_n^m are calculated using the recursion relation (29:24):

$$xP_n^m(x) = \epsilon_{n+1}^m P_{n+1}^m (x) + \epsilon_n^m P_{n-1}^m (x) \qquad (III-23)$$

where (29:24):

$$\epsilon_n^m = \left[\frac{n^2 - m^2}{4n^2 - 1} \right]^{\frac{1}{2}} \qquad (III-24)$$

The values for ϵ_n^m are evaluated in subroutine EPSLON, while the P_n^m functions are evaluated in subroutine PLN3. These subroutines were taken directly from Hopkin's code.

A real, smooth function $F(\lambda, \theta)$ that is defined for all values of λ and θ over a sphere can be expressed as the sum of a series of orthonormal functions as shown (13:146,9:263):

$$F(\lambda, \theta) = \sum_{m=-\infty}^{\infty} \sum_{n=|m|}^{\infty} F_n^m Y_n^m \qquad (III-25)$$

where F_n^m are complex expansion coefficients and Y_n^m is defined by Equation III-20. However, from the definition

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of P_n^m in Equation III-22, P_n^m is zero for $|m| > n$ (20:737).
Thus, the summation in Equation III-25 can be limited as
follows:

$$F(\lambda,\theta) = \sum_{m=-n}^{n} \sum_{n=|m|}^{\infty} F_n^m Y_n^m \qquad \text{(III-26)}$$

Since the summation limits must be finite for the program
to compute values for the variables, the limits are set to
a number J such that (29:25):

$$F(\lambda,\theta) = \sum_{m=-J}^{J} \sum_{n=|m|}^{|m|+J} F_n^m Y_n^m \qquad \text{(III-27)}$$

The truncated summation in Equation III-27 is known as a
rhomboidal truncation because plotting the numbers n versus
m results in a rhomboid shape (See Fig. III-3). Rhomboidal
truncation is used in this situation because it allows the
wind vectors to be resolved to the same degree in both the λ
and θ directions (29:2). In HYDRA, J is set to 30, the
same truncation limit used in atmospheric models at the
National Meteorological Center.

Using Equation III-27, U and V can be represented by
the following equation (28:1284):

$$(U,V) = \sum_{m=-J}^{J} \sum_{n=|m|}^{|m|+J+1} (U_n^m, V_n^m) Y_n^m \qquad \text{(III-28)}$$

where the summation has been modified slightly to keep the
U and V terms compatible with other atmospheric variables
using the truncation limits of Equation III-27 (28:1284).

One further simplication of the summation limits may
be made. The summation over m may be broken down as fol-

33
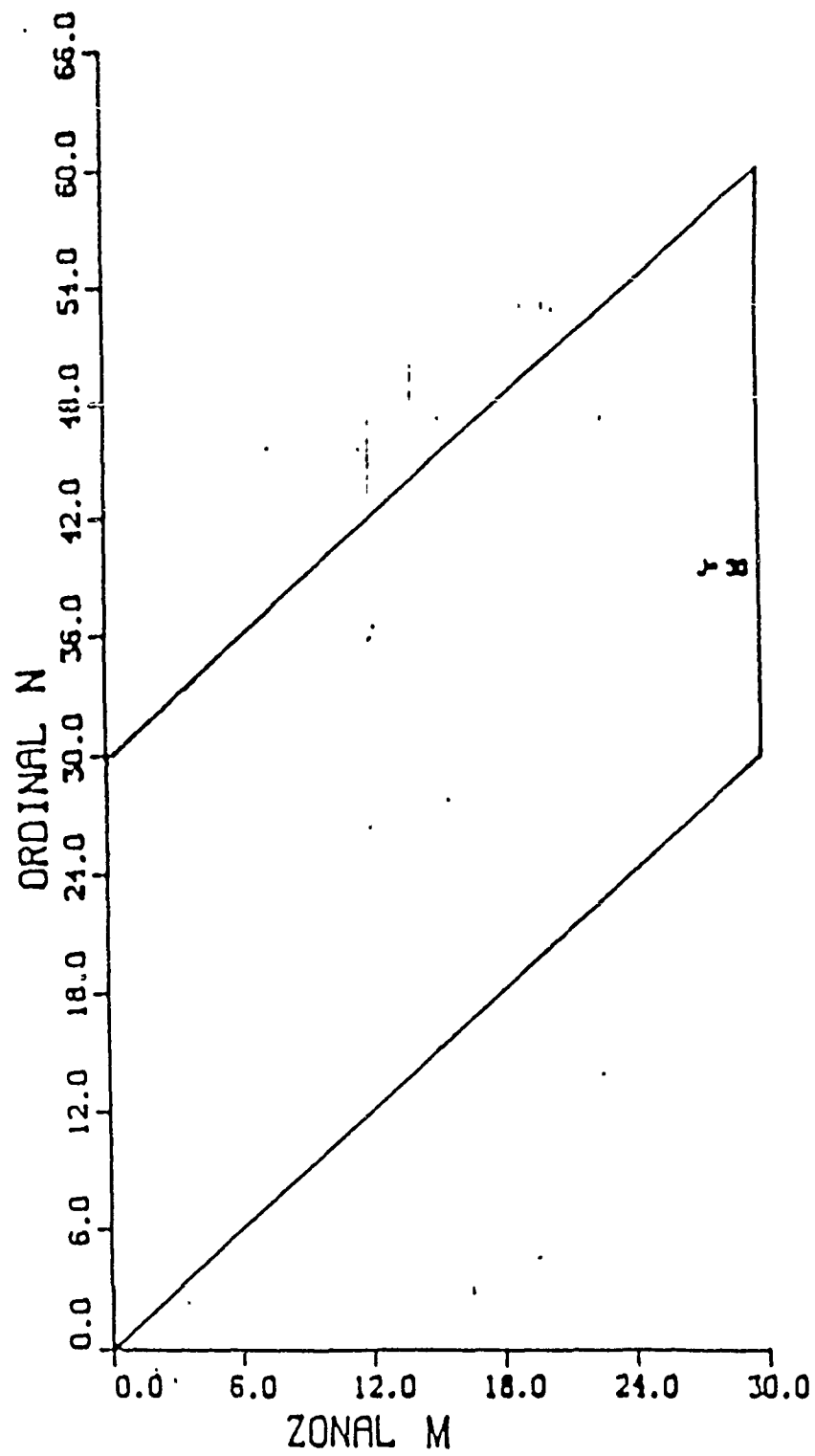
Fig. III-3. Spectral Domain
Using a Rhomboidal Truncation (24:13)

lows (15:122):

$$\sum_{m=-J}^{J} = \sum_{m=-J}^{-1} + \sum_{m=0}^{0} + \sum_{m=1}^{J} \qquad \text{(III-29)}$$

The summation over the negative values of m can be rewritten as (15:122):

$$\sum_{m=-J}^{-1} \sum_{n=|m|}^{|m|+J+1} (U_n^m, V_n^m) Y_n^m = \sum_{m=1}^{J} \sum_{n=m}^{m+J+1} (U_n^{-m}, V_n^{-m}) Y_n^{-m} \qquad \text{(III-30)}$$

However, since U and V are real, physical quantities, the spectral coefficients (U_n^{-m}, V_n^{-m}) can be represented as (29:25):

$$(U_n^{-m}, V_n^{-m}) = (-1)^m (U_n^m, V_n^m)^* \qquad \text{(III-31)}$$

where $(U_n^m, V_n^m)^*$ are the complex conjugates of the spectral coefficients. Likewise (15:123):

$$Y_n^{-m} = (-1)^{-m} (Y_n^m)^* \qquad \text{(III-32)}$$

where $(Y_n^m)^*$ is the complex conjugate of Y_n^m. The summation over the negative values is then (15:123):

$$\sum_{m=1}^{J} \sum_{n=m}^{m+J+1} (U_n^{-m}, V_n^{-m}) Y_n^{-m} =$$
$$\sum_{m=1}^{J} \sum_{n=m}^{m+J+1} (U_n^m, V_n^m)^* (Y_n^m)^* \qquad \text{(III-33)}$$

Since U and V are real quantities, only the real part of Equation III-33 is used (15:123):

$$\text{Re} \sum_{m=1}^{J} \sum_{n=m}^{m+J+1} (U_n^m, V_n^m)^* (Y_n^m)^* =$$
$$\text{Re} \sum_{m=1}^{J} \sum_{n=m}^{m+J+1} (U_n^m, V_n^m) Y_n^m \qquad \text{(III-34)}$$

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This is equivalent to the real part of Equation III-28 when summed over positive values of m. Therefore, the final form for U and V can be given by the formula (15:124):

$$(U,V) = Re \sum_{m=0}^{J} \sum_{n=m}^{m+J+1} A(U_n^m, V_n^m) Y_n^m \qquad (III-35)$$

where $A = 1$ if $m = 0$ and $A = 2$ for nonzero values of m. Equation III-35 is the formula used in HYDRA to calculate the wind components at a given spectral layer altitude, and is found in subroutine UVCOMP, which was taken directly from Hopkin's code. Wind velocity components at altitudes other than the spectral layer altitudes are linear interpolations of the wind components of the spectral layers which bound that altitude.

Dose Rate Calculations

Dose rate calculations are performed assuming the cloud distribution is Gaussian in the horizontal and vertical directions. HYDRA uses Equation II-1 to determine the dose rate both on and off the hotline, but the final form is different from that used in WSEG-10 and the AFIT model because of the curved hotline. The final form is (14:82):

$$\dot{D}_1(x,y) = \frac{(K)(Y_k)(FF)g(t_a)}{\sqrt{2\pi}} \left[\frac{\sigma_y^2 X^2}{t_a^2} + \frac{\sigma_x^2 Y^2}{t_a^2} \right]^{-\frac{1}{2}}$$

$$* \quad EXP \left[-.5 \left(\frac{(xY - yX)^2}{\sigma_y^2 X^2 + \sigma_x^2 Y^2} \right) \right] \qquad (III-36)$$

where (X,Y) is the particle arrival point on the hotline

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and (x,y) is a point off the hotline. This form arises mainly because the $v_x t'$ and $v_y t'$ terms, where v_x and v_y are constants, are replaced with the integrals (14:73):

$$v_x t' \Rightarrow \int_0^{t'} v_x \, dt'$$
$$v_y t' \Rightarrow \int_0^{t'} v_y \, dt'$$

For a detailed derivation of Equation III-36, see Reference 14, p73-82. A comparison of Equation III-36 with Equation II-9 will show that the term raised to the $-\frac{1}{2}$ power in Equation III-36 is functionally equivalent to the $\sigma_y(t') v_x$ term in Equation II-9.

Equation III-36 models the grounded activity as a Gaussian distribution centered about the hotline. St Ledger showed that this Gaussian distribution lies on a straight line that is perpendicular to a line extending from ground zero to a particle arrival point on the hotline (30:32-35). This straight line passes through the arrival point, and its equation is given by:

$$y = (-X/Y)x + Y + (X^2/Y) \tag{III-37}$$

In calculating contour points off the hotline, the dose rate $\dot{D}_1(x,y)$ is known and it is the coordinates x and y which must be found. Substituting Equation III-37 into Equation III-36 yields the coordinate x as a function of $\dot{D}_1$, X, Y, Y_k, K, σ_x, σ_y, and t_a. The coordinate y can then be found using Equation III-37.

The terms $\sigma_x(t_a)$ and $\sigma_y(t_a)$, the cloud deviations in

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the x and y directions, arise from the toroidal motion in the cloud and from wind shear (4). The equation for these terms is (4):

$$\sigma_{x,y}^2 (t_a) = \sigma_o^2 \left[1 + \frac{8t^*}{T_c} \right] + \left[\frac{S_{x,y}\, t_a\, \sigma_z}{2} \right]^2 \qquad \text{(III-38)}$$

where $S_{x,y}$ is the shear in the x or y direction and t_a is the particle arrival time in hours. The first term on the right hand side of Equation III-38 accounts for toroidal growth while the second term accounts for the shear.

The toroidal term is empirical and is taken from WSEG-10 (4). t^* is equal to three hours or the particle arrival time, whichever is less. This limit on t^* represents the time at which toroidal motion is assumed to no longer have any effect on the cloud spread (12:7). The initial cloud spread σ_o is given by (25:51):

$$\sigma_o = 1.609 \text{EXP} \left[.70 + \ln Y_m/3 - \frac{3.25}{4.0 + (\ln Y_m + 5.4)^2} \right] \qquad \text{(III-39)}$$

where Y_m is the yield in megatons and σ_o is in kilometers. The quantity T_c is also empirical and is given by (25:51):

$$T_c = (H_c/5.0) - 2.5(H_c/60.0)^2 \qquad \text{(III-40)}$$

where T_c is in hours and H_c is the particle injection height given by Equation III-5 and converted to kilofeet.

The shear term is derived in Reference 26. σ_z is the

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cloud spread in the vertical direction and is given by (25:51):

$$\sigma_z = (1.609/5.28)(.18H_c) \qquad (III-41)$$

where σ_z is in kilometers. $S_{x,y}$ has units of inverse hours.

To have a closed dose rate contour, the user-specified contour value must be located twice on the hotline. One point will be near ground zero and the other point will be located somewhere further down the hotline. These points are found by calculating the dose rates at the particle arrival points and then linearly interpolating between the points. The dose rate at ground zero is assumed to be zero for calculational purposes, even though it is not physically realistic for a surface burst.

Dose Rate Contour Mapping

The hotline and contour points are stored in the output file DOSERTE. DOSERTE is the input file to program HYDMAP. HYDMAP converts the coordinates in DOSERTE from kilometers to degrees longitude and degrees latitude and then overlays these points on maps. HYDMAP automatically selects the range in longitude and latitude for the plots.

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IV. Evaluation and Results

Overview

The theory and equations presented in the previous section are very similar and in many cases identical to those used in another variable wind smear code, REDRAM. REDRAM was written by Arthur Hopkins, and was the first fallout code to use the spectral coefficient method.

REDRAM was validated against data from the Mt. St. Helens volcanic eruption and from a small conventional explosives test called DIRECT COURSE. Mt. St. Helens was taken to be representative for a debris cloud from a nuclear explosion in the megaton range, since the ash cloud rose to a height of 22 kilometers. In the DIRECT COURSE test, the Defense Nuclear Agency detonated 600 tons of high explosives. Thus, the data was representative of a nuclear explosion in the kiloton range. Agreement in both cases between the observed and REDRAM-calculated hotline locations and particle trajectories was excellent. Hopkins also determined that the contribution to the total dose rate error from the spectral coefficients was approximately four percent. (15:57-58,112)

The accuracy of HYDRA was evaluated by comparing HYDRA output with REDRAM output for nine test cases. The test cases are summarized in Table IV-1.

Table IV-1
Summary of Test Cases Used In Evaluating HYDRA

Shot #	Yield (Kt)	Location of Ground Zero Deg. Long.	Deg. Lat.
1	500	45.000	-30.000
2	100	354.000	46.000
3	1000	58.000	75.000
4	100	170.000	-40.000
5	100	253.525	33.624
6	100	165.230 ...	11.350
7	1000	37.600	58.000
8	500	90.000	15.000
9	500	300.000	-60.000

All test cases in Table IV-1 used the following data:

1. The spectral coefficients were derived from "typical" winds for January 14, 1978.

2. Median particle radius = 0.204 microns. (DELFIC default).

3. Logarithmic slope = ln(4.0) (DELFIC default).

4. Fraction of the particle activity located in the particle volume = 0.68 (from DELFIC).

5. Particle density = 2600.0 kg/m^3.

6. Fission fraction = 0.5.

7. Source normalization constant = 6084.0 roentgen-km^2/hr-kt (from DELFIC).

Plots comparing the contour maps produced by each code are given in Figures IV-1 and IV-2 for test cases 2 and 3. Comparison plots for the remaining cases are given in Appendix A. Overall, the agreement between HYDRA and REDRAM is excellent, with identical hotlines being produced in all runs. The differences in X and Y coordinates, shear terms, and arrival times were less than 0.5%.

In all runs, the calculation of the point where a con-

Fig. IV-1. Test Case 2: HYDRA vs. REDRAM
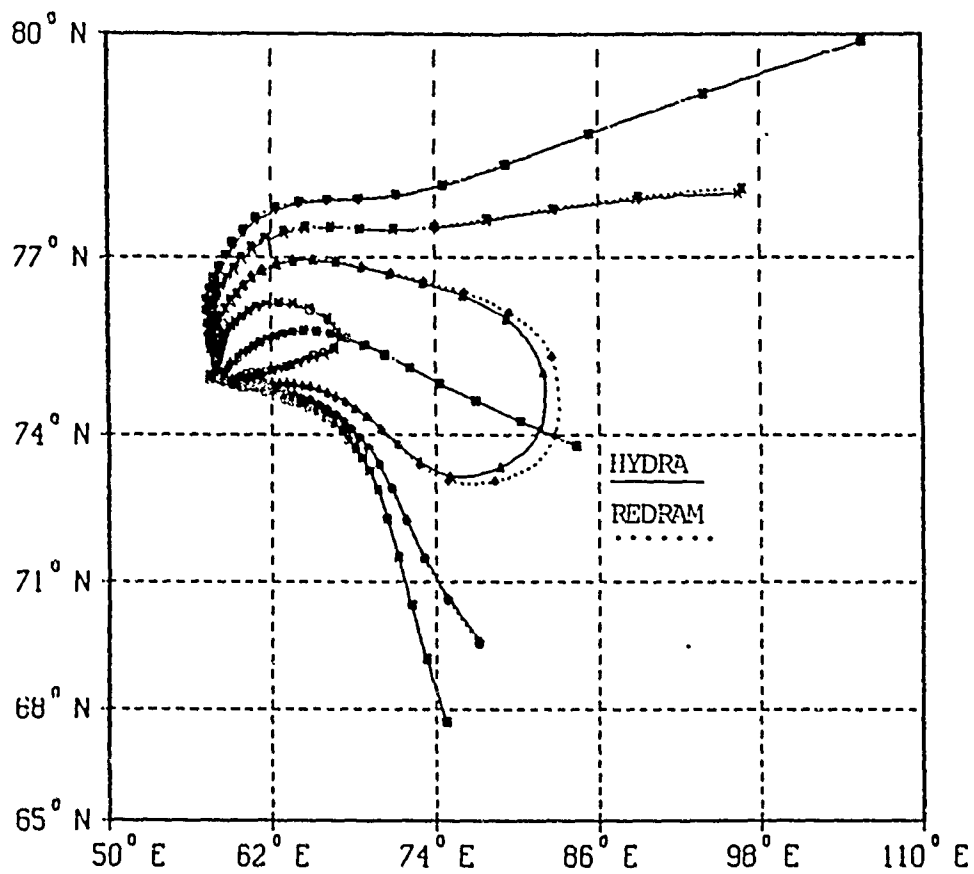
Fig. IV-2. Test Case 3: HYDRA vs. REDRAM

tour crossed the hotline produced the largest differences
between the two models. These differences are summarized
in Table IV-2. The distance from ground zero was deter-
mined using HYDRA data. The error listed in Table IV-2 was
calculated by dividing column 2 by column 3.

Table IV-2
Largest Differences in Test Cases

Shot #	Largest Distance (Km)	Distance from GZ (Km)	% Error
1	37.426	1211.109	3.09
2	115.171	2498.814	4.61
3	40.807	726.159	5.62
4	64.355	1494.749	4.31
5	51.675	1200.397	4.30
6	16.398	502.951	3.26
7	58.387	1773.009	3.29
8	25.657	747.419	3.43
9	71.332	1530.939	4.66

Differences between the contour maps produced by the
codes arise from two main sources:

1. In calculating dose rates, REDRAM models the
    cloud as a single flat pancake cloud, while
    HYDRA models the cloud as a set of pancake
    clouds, one cloud for each particle size.

2. Different methods are used to calculate $g(t)$.

Each of these differences is discussed in one of the follow-
ing sections.

Single Versus Multiple Pancake Clouds

At very high and very low yields, HYDRA and REDRAM do
not agree well. The contours produced by HYDRA are shorter
and fatter than those produced by REDRAM. Other than the

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g(t) function, the major difference between the two codes lies in the calculation of the vertical cloud distribution σ_z and of the quantity T_c. REDRAM uses the single cloud height of Equation II-3 in these calculations, while HYDRA uses a different cloud height for each particle size as determined by Equation III-5.

To determine the effects of using a single pancake cloud (SPC) as opposed to multiple pancake clouds (MPC), a second version of HYDRA, called HYDRAS, was created that used Equation II-3 to calculate σ_z and T_c. Test cases for various yields at the location of test case 6 were run on the two codes. Results are displayed in Appendix B, and show that HYDRA and HYDRAS produce nearly identical contours for yields in the "critical" range of 10 kilotons to 2.0 megatons. Outside this range, however, the contours for the multiple cloud model start to spread, with the spread increasing as the yield gets larger or smaller. The explanation for this behavior must lie in the calculation of $\sigma_{x,y}$ (Eqn III-38), because it is the only calculation dependent on the values of σ_z and T_c.

σ_z as a function of arrival time is plotted in Figures IV-3 through IV-5 for both cloud models for yields of 1, 500, and 15000 kilotons, respectively. In all three figures, the value of σ_z for the MPC model rises rapidly from a low value to some limiting value. This limiting value is dependent on the weapon yield.

For the yield inside the critical range, the limiting

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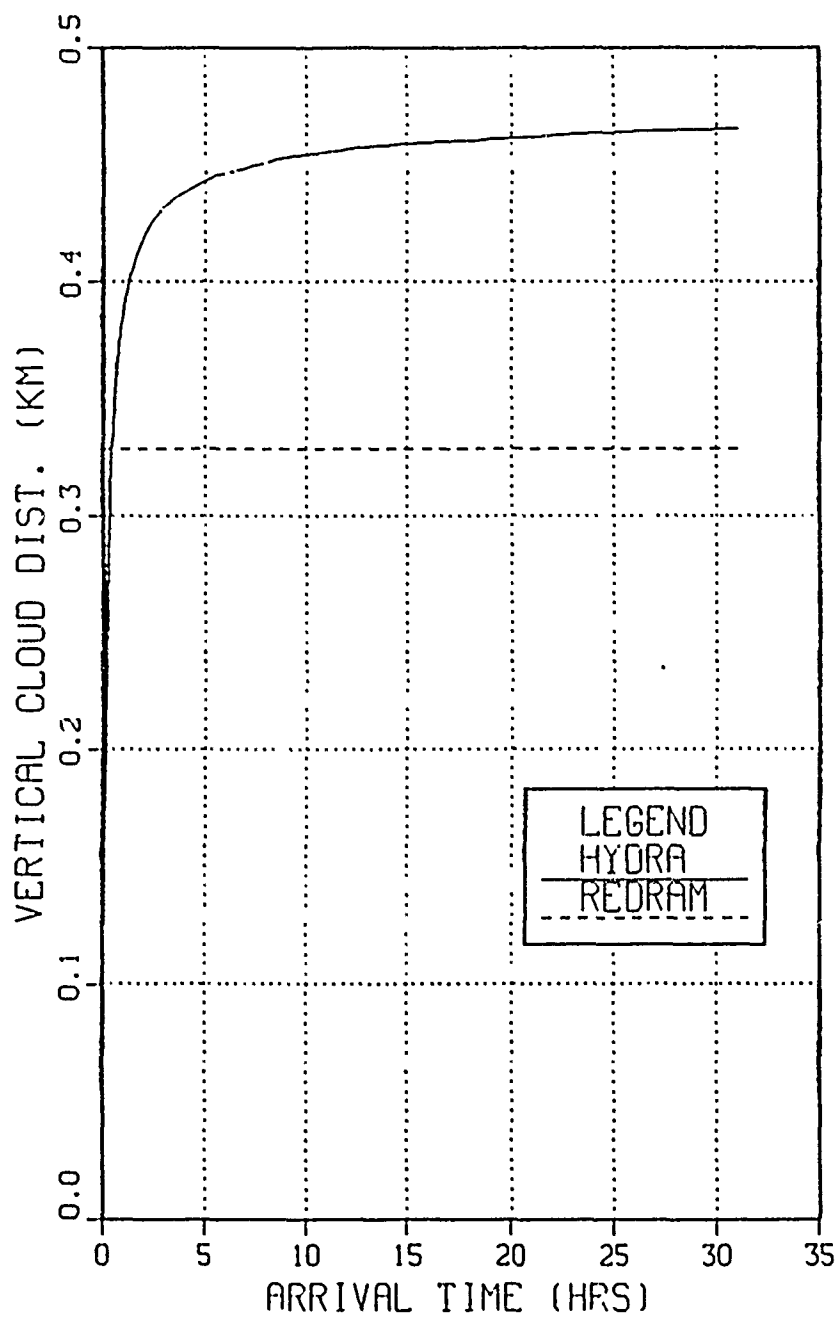
Fig. IV-3. Vertical Cloud Distribution vs. Arrival Time

For a 1 Kiloton Burst
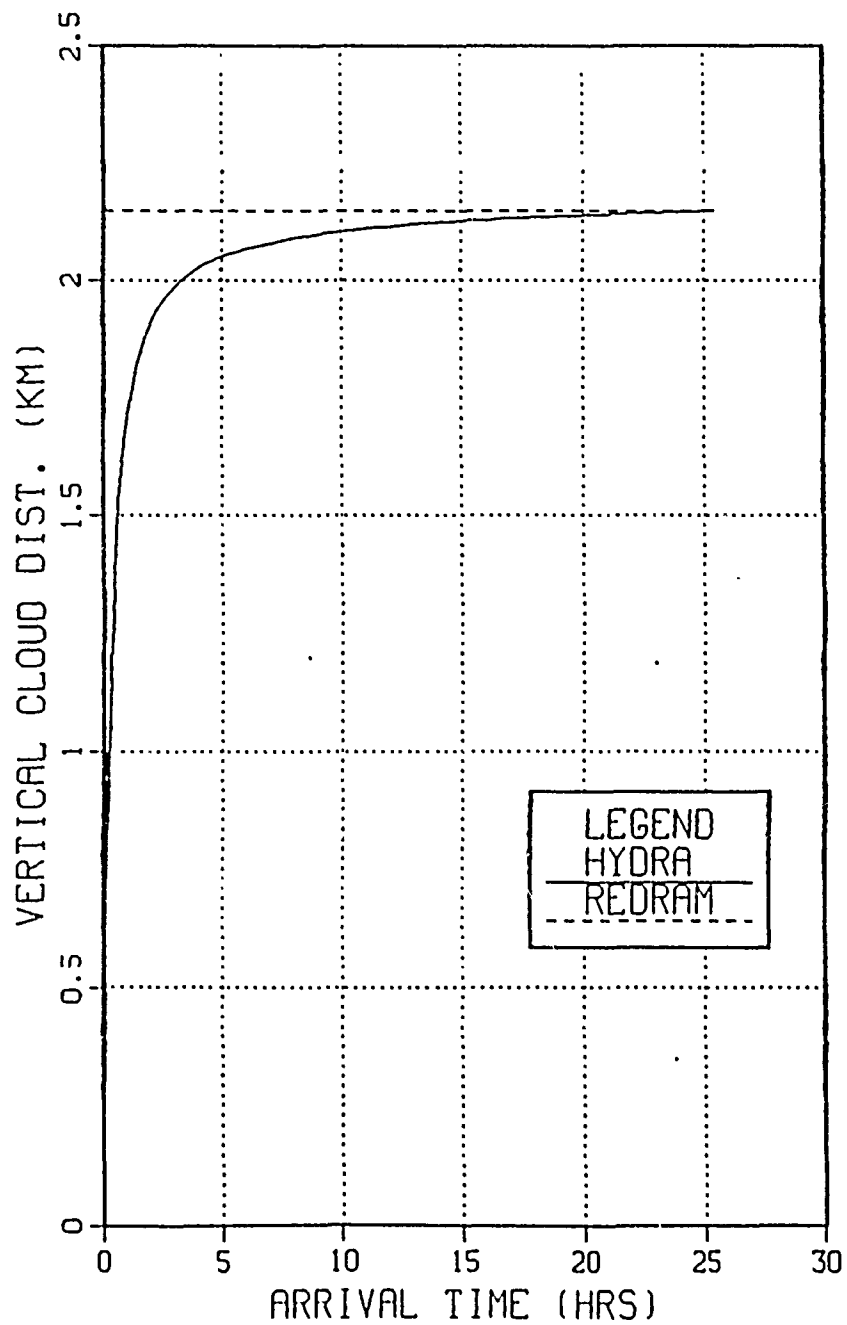
Fig. IV-4. Vertical Cloud Distribution vs. Arrival Time

For a 500 Kiloton Burst

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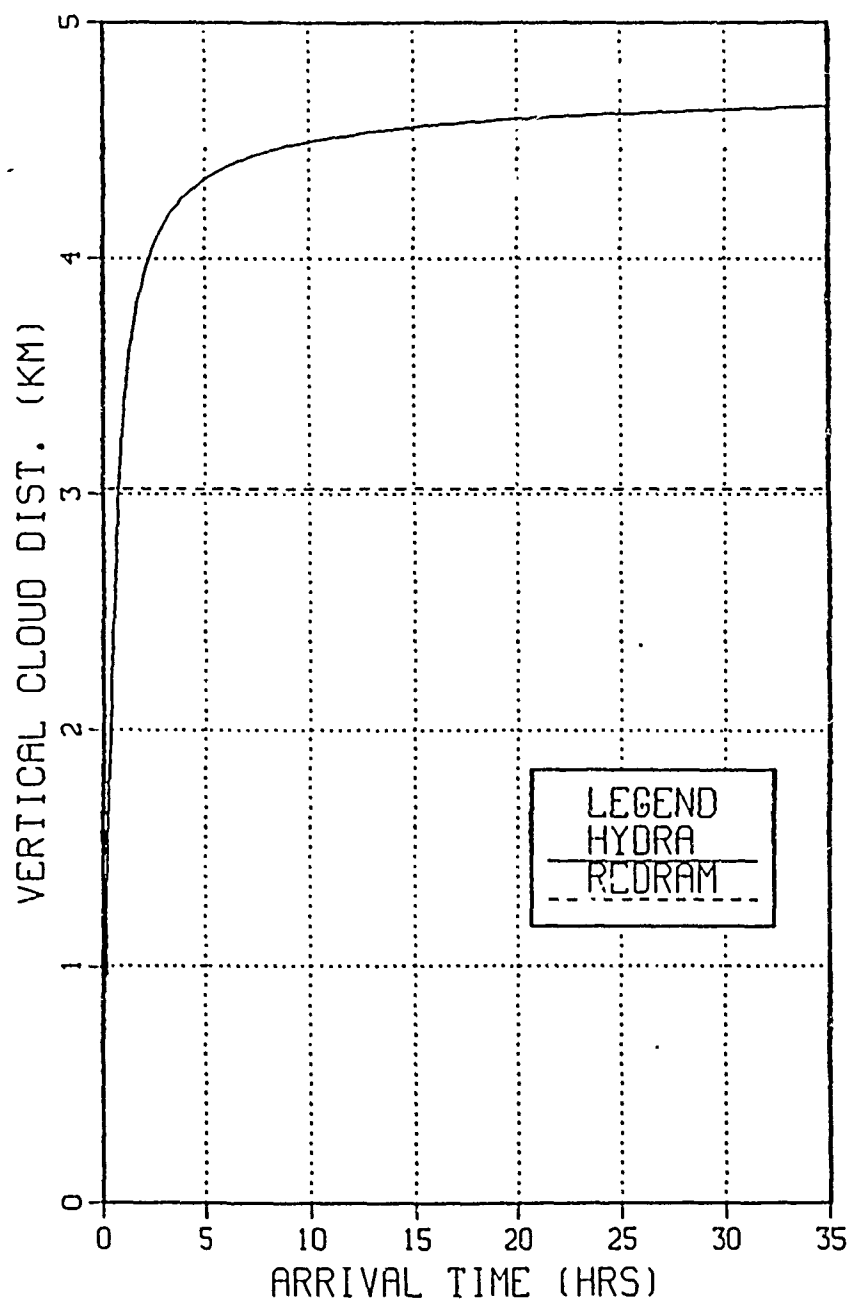
Fig. IV-5. Vertical Cloud Distribution vs. Arrival Time

For a 15 Megaton Burst

value of σ_z for the MPC model is the value of σ_z given by the SPC model. For an arrival time of five hours, the MPC σ_z value is already at 95 percent of the SPC value. Therefore, because the MPC value rises so rapidly to the SPC value, little difference is seen in the contours for yields in the critical range, especially for late arrival times.

For yields outside the critical range, the difference in σ_z between the two models becomes very large for arrival times greater than five hours. The ratio of the MPC σ_z value to the SPC value for the 1 kiloton burst ranged from 1.35 to 1.41, while that of the 15 megaton burst ranged from 1.43 to 1.54. The larger σ_z value results in much larger deviations in the horizontal cloud distribution (See Eqn III-38) for the MPC model as compared to the SPC model. Thus, at any given point on the hotline, the dose rate in the MPC model will be less than that in the SPC model (See Eqn III-36), resulting in a shorter contour pattern in the MPC model. However, since the deviations in the cloud distribution are so much larger, the contour patterns in the MPC model will also be much wider than those for the SPC model. Figure B-1 in Appendix B is the most dramatic example of the differences in the contour patterns of the two models.

The relationship between T_c and arrival time for the two models is very similar to the one observed between σ_z and arrival time. However, the effects of large differences in T_c are small compared to those achieved by the

differences in σ_z. The value of T_c affects only the
toroidal term of Equation III-38, which contributes very
little to the horizontal spread of the cloud for arrival
times greater than three hours.

Calculation of g(t)

Both models use Equation III-11 to calculate g(t), but
employ different methods to determine the quantity dr/dt.
REDRAM uses Colarco's coefficients to determine dr/dt,
while HYDRA uses Equation III-12. Plots of g(t) versus
arrival time are given for runs 2 and 3 in Figures IV-6 and
IV-7. From these plots it is seen that using the method of
Equation III-12 produces a lower value for g(t) for most
arrival times than do Colarco's coefficients. This results
in lower dose rates along the hotline and causes the con-
tour lines to lie closer to the hotline. An inspection of
Figures IV-1 and IV-2 and the plots in Appendix A shows
that the HYDRA contour lines lie inside the REDRAM contour
lines in every test case.

In test cases 2 and 3, the differences between the con-
tour maps were quite large for locations far from the burst
site. To determine if the g(t) calculations were responsi-
ble for these differences, a third version of HYDRA, named
HYDRAC (C for Colarco), was created that used Colarco's
coefficients to calculate g(t). Test cases 2 and 3 were
run through HYDRAC, and the results were compared to the
REDRAM output. These results, displayed in Figures IV-8
and IV-9, show that the differences between the two models

50
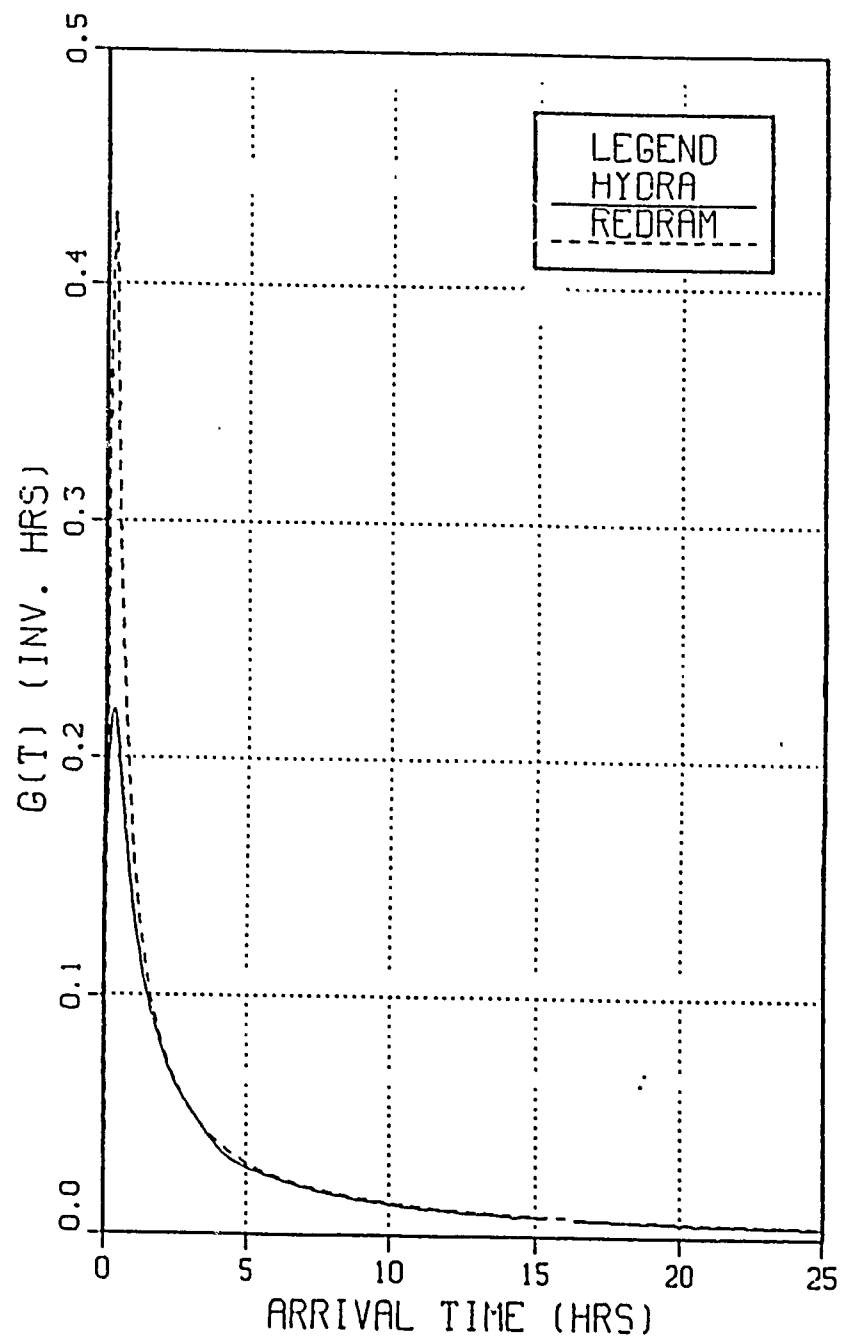
Fig. IV-6. g(t) vs. Arrival Time for Test Case 2 (100 Kt)
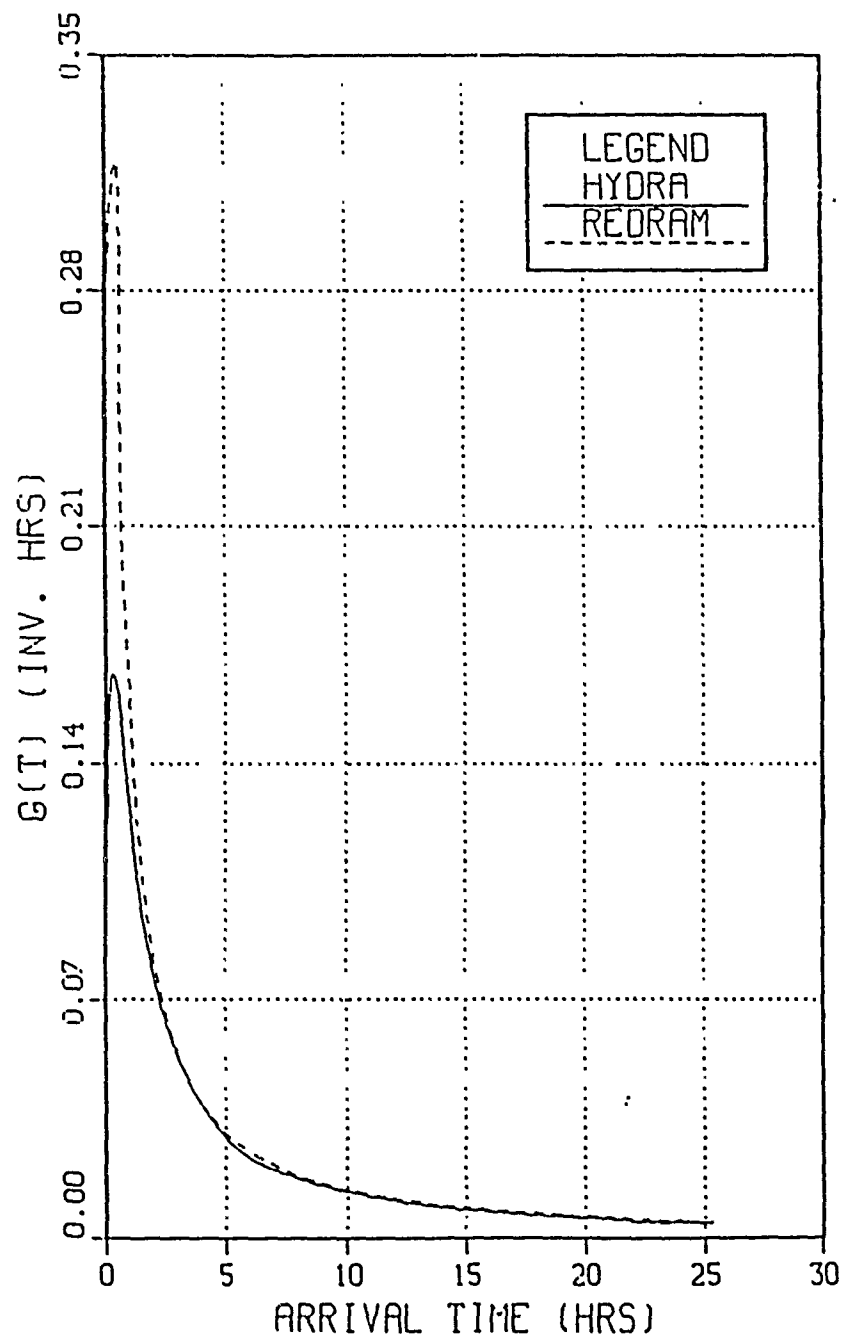
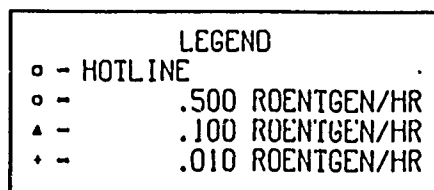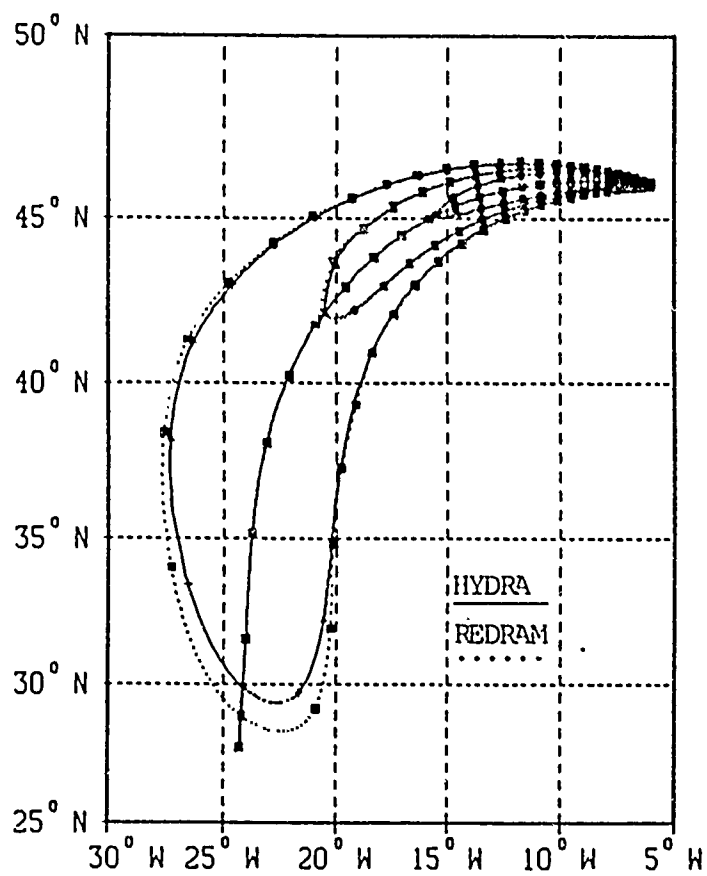Fig. IV-7. g(t) vs. Arrival Time for Test Case 3 (1 Mt)
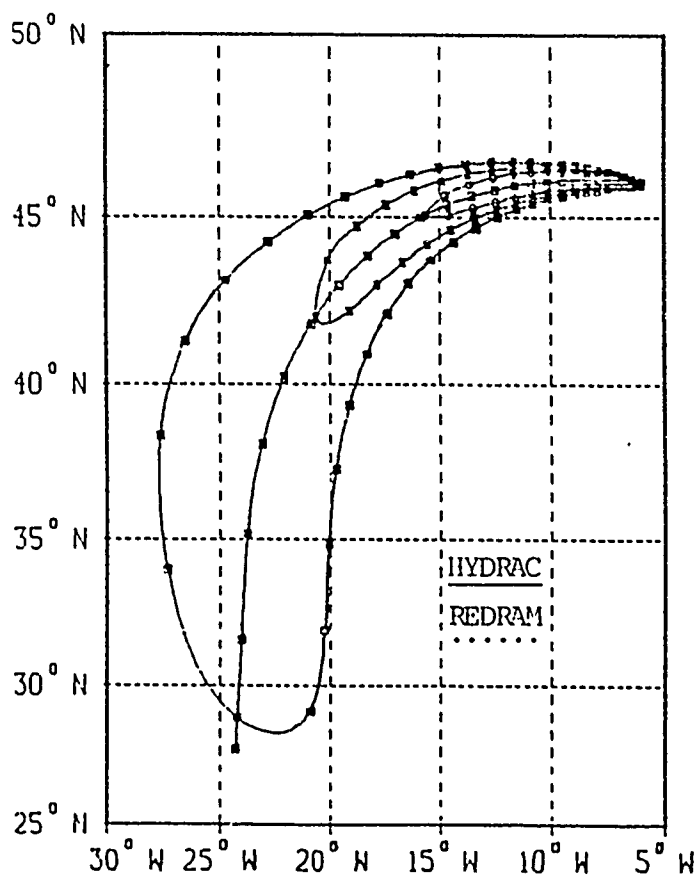
Fig. IV-8. Test Case 2: HYDRAC vs. REDRAM
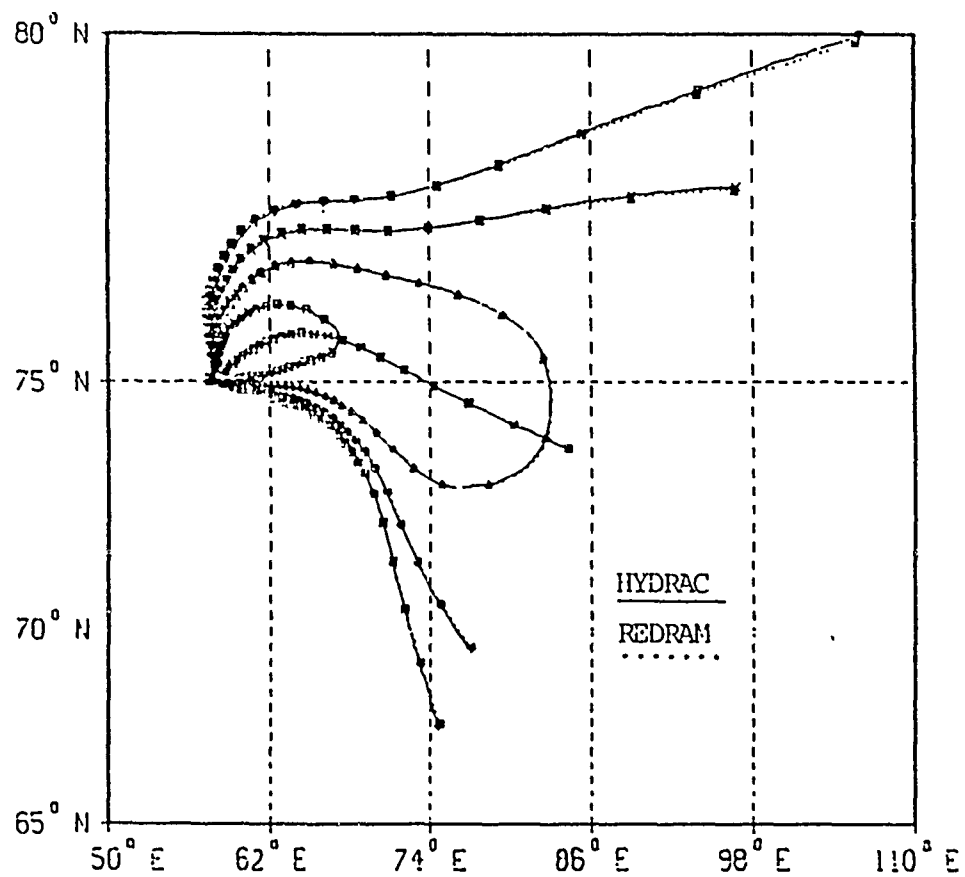
LEGEND
- □ = HOTLINE
- ○ = 10.000 ROENTGEN/HR
- △ = 1.000 ROENTGEN/HR
- • = .100 ROENTGEN/HR
- × = .100 ROENTGEN/HR
- • = .010 ROENTGEN/HR
- ▼ = .010 ROENTGEN/HR

Fig. IV-9. Test Case 3: HYDRAC vs. REDRAM

have been almost completely eliminated. Thus, the g(t) calculations are the main source of the differences observed in the contour patterns for yields ranging from 10 kilotons to 2 megatons. Outside this range, the different cloud models used in the two codes may cause large differences in the contour patterns.

The slight differences observed in Figure IV-9 can be eliminated by replacing the multiple pancake cloud model in HYDRAC with the single pancake cloud model. This was done for test case 3, and the contour patterns produced by the two codes were indistinguishable when plotted.

Changing the size of the "bounding" particle radii, R2 and R1, in Equation III-12, from 1.01 X (radius) and 0.99 X (radius) to 1.005 X (radius) and 0.995 X (radius), respectively, had no effect on the value of dr/dt. The values of dr/dt were the same out to four or five decimal places.

In addition to determining dr/dt, Colarco's coefficients also calculate the radius of the particle hitting the ground for a given arrival time. Thus, a good way to check the accuracy of Colarco's coefficients is to compare the Colarco radii with the radii used to determine the hotline. Ideally, the two sets of radii should be identical. The ratio of the actual particle radius to the Colarco radius is plotted as a function of arrival time for three different yields in Figure IV-10. This plot shows that, for yields ranging from 100 to 1000 kilotons, Colarco's coefficients almost always underestimate the particle size for

55
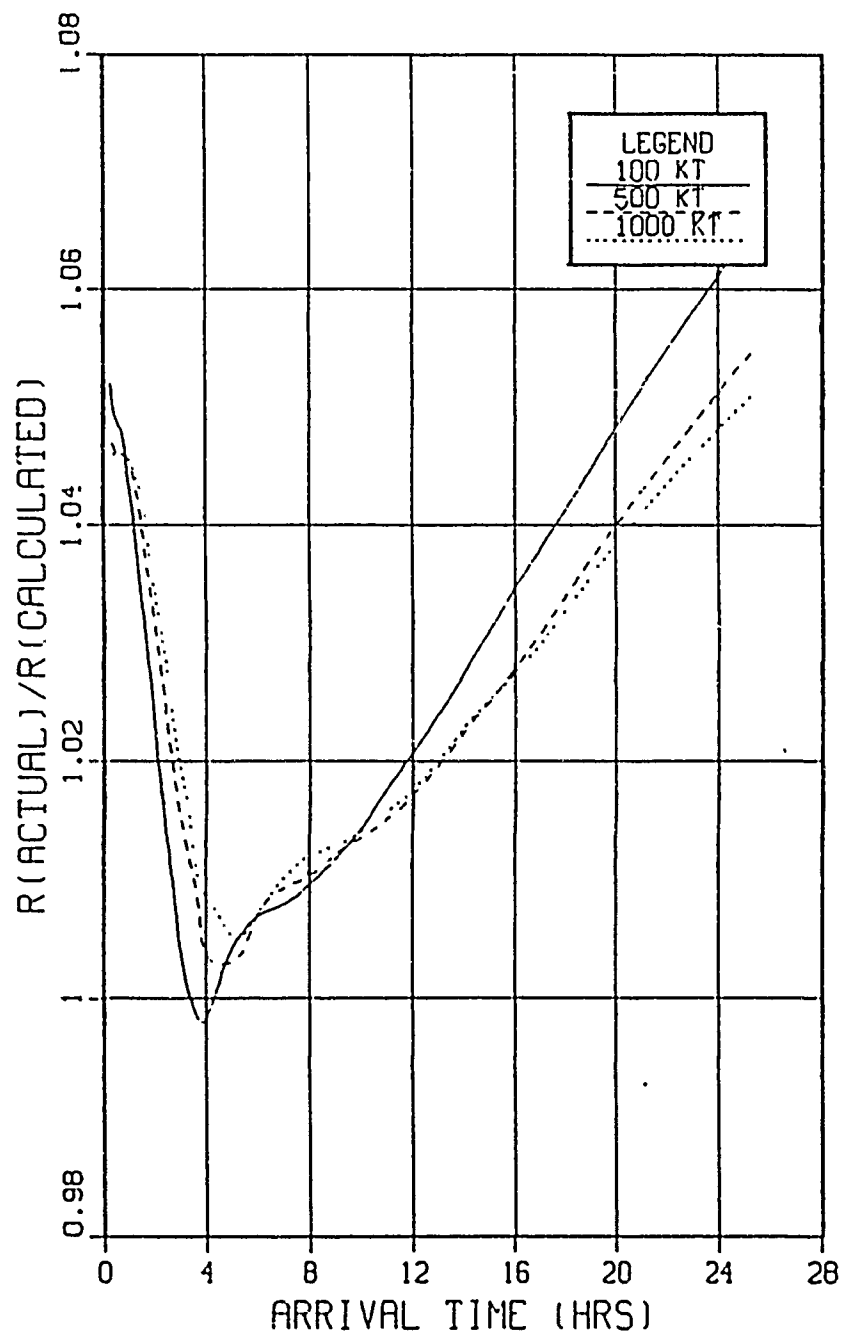
Fig. IV-10. Actual-to-Calculated Particle Size Ratio
vs. Arrival Time for Various Burst Sizes

arrival times out to 24 hours. Colarco's coefficients are most accurate for arrival times ranging from 2.0 to 12.0 hours (accurate to within 2%), with differences of up to 6% for arrival times outside this range. Thus, all other parameters being equal, any code using Colarco's coefficients will be less accurate than HYDRA, since HYDRA uses the actual particle sizes to calculate dr/dt rather than empirically fit coefficients.

Optimum Number of Particles

The optimum number of particles is the one that will reproduce the hotline and contours with a fair degree of accuracy while using as little computing time as possible. This optimum number was determined by comparing the contour patterns produced by 10-, 15-, and 20-particle runs with 25-particle runs. Comparisons were done for test cases 2,3,4, 5,7, and 9. Little difference was observed in the contour patterns produced by the 15-, 20-, and 25-particle runs. However, the 10-particle runs were generally at considerable variance with the other runs with test case 4 producing the worst agreement. Thus, it can be concluded that at least 15 particles are needed to accurately determine the hotline and contour patterns. Contour comparisons for test case 4 are presented in Figures IV-11 through IV-13.

Capabilities and Limitations

HYDRA and HYDMAP together are capable of producing contour patterns overlayed on maps anywhere in the world.

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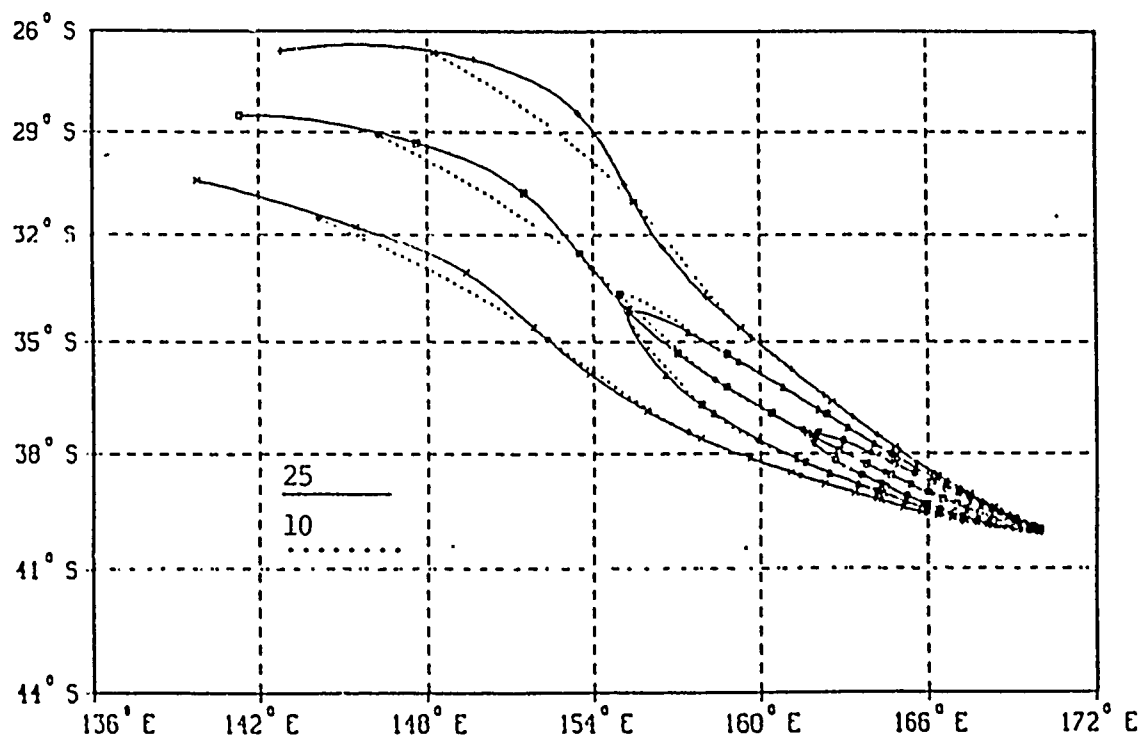
Fig. IV-11. HYDRA Results: 25 Particles vs. 10 Particles
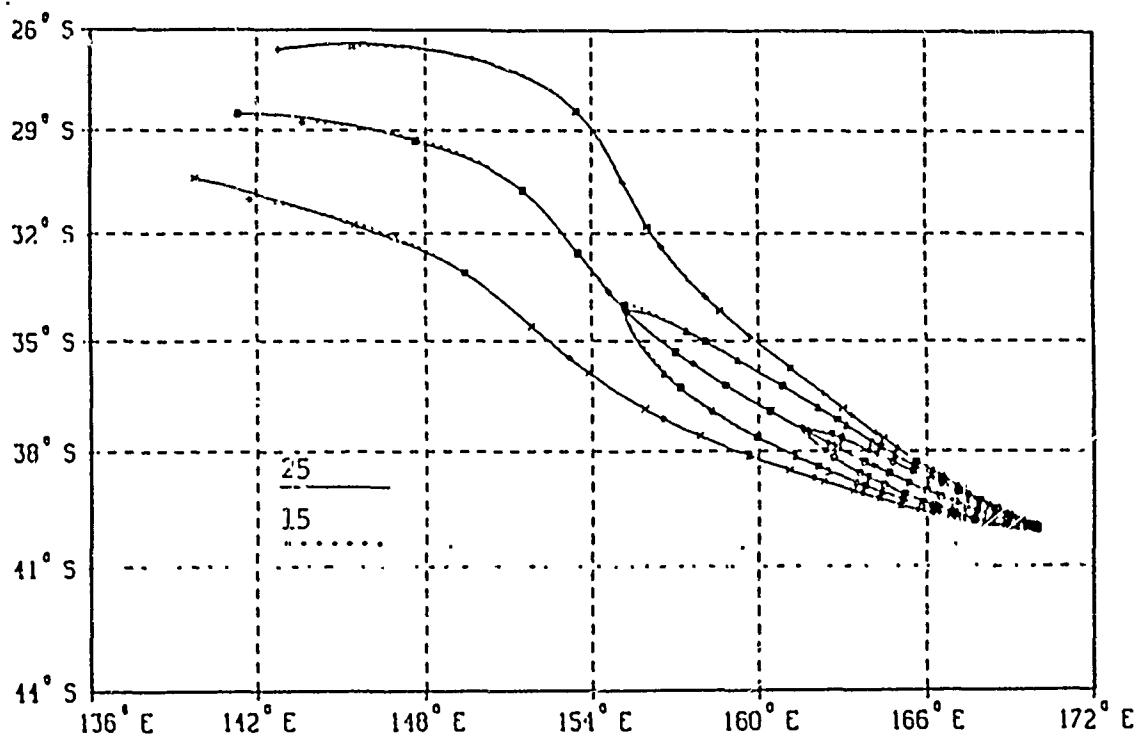
Fig. IV-12. HYDRA Results: 25 Particles vs. 15 Particles

LEGEND
□ - HOTLINE
o -   .500 ROENTGEN/HR
▲ -   .100 ROENTGEN/HR
+ -   .010 ROENTGEN/HR
× -   .010 ROENTGEN/HR
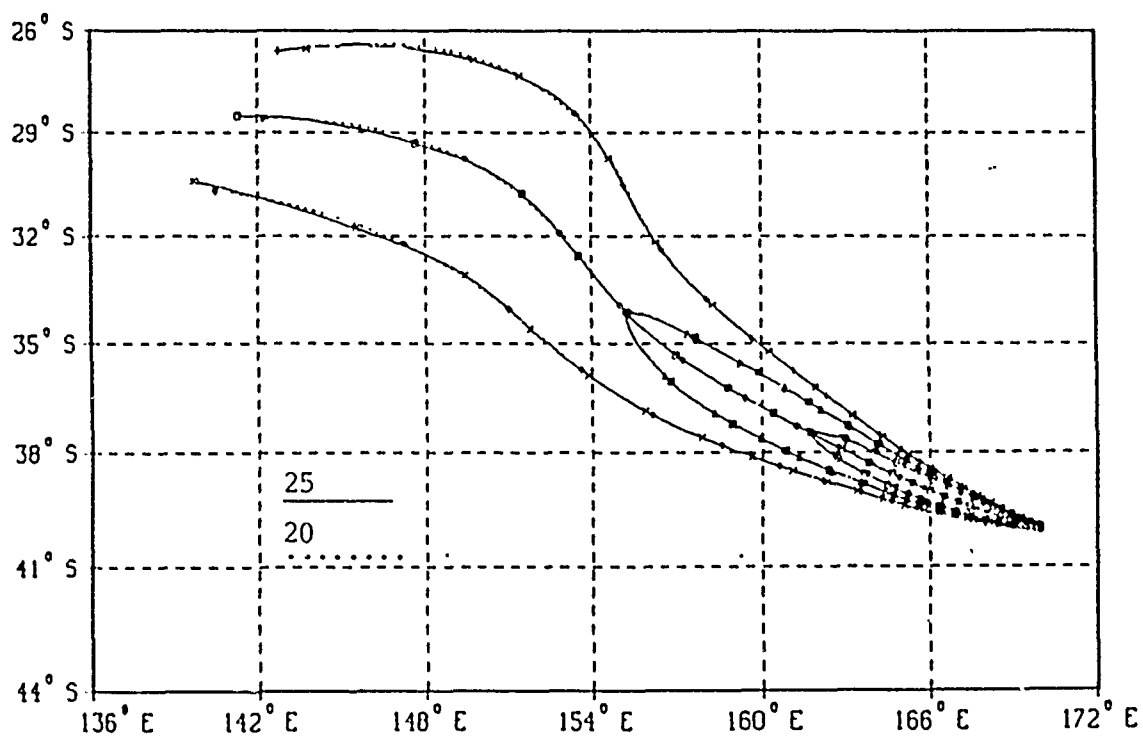
Fig. IV-13. HYDRA Results: 25 Particles vs. 20 Particles

Test cases 1 through 9 are plotted with maps in Figures C-1 through C-9 in Appendix C.

The contour patterns and hotlines produced by HYDRA are most reliable in the northern hemisphere for latitudes ranging from 10 to 80 degrees. The data points needed to create spectral coefficients are sparse at the equator, and are not available at all in the southern hemisphere. The test cases in the southern hemisphere used wind patterns that are mirror images of the ones in the northern hemisphere. (16)

For best results, the weapon yield should be limited to 10 megatons or less. Otherwise, the particle injection height is above the highest spectral level, and winds can no longer be interpolated between the spectral levels.

V. Summary, Conclusions, and Recommendations

Summary and Conclusions

A radioactive fallout prediction code, HYDRA, has been developed that uses real winds to give realistic dose rate contours for single nuclear bursts at the earth's surface. HYDRA divides the stabilized radioactive dust cloud into a user-specified number of particle size groups that are gravity-sorted within the cloud. All particles are assumed to be spherical in shape, and are transported to the ground using McDonald-Davies fall mechanics in a discretely layered atmosphere. Horizontal transport of the particles is accomplished using real winds. These winds are represented as sums of orthogonal functions in spherical coordinates, using a method first developed at the National Meteorological Center.

The connection of the particle arrival points for each particle size group forms the hotline. Contour patterns about the hotline are determined by assuming that the activity distribution about the hotline has a Gaussian form, with the peak of the Gaussian on the hotline.

HYDRA is designed for local fallout prediction (24 hours or less). It is capable of predicting fallout patterns anywhere in the world except for the poles. However, the best results will be achieved by limiting the burst locations to the northern hemisphere from 10 to 80 degrees north latitude. No wind data is currently available for the southern hemisphere, and the wind vectors at the equa-

tor are not reliable due to the scarcity of data there. At least 15 particles are needed to adequately define the hot-line and contour patterns.

HYDRA was validated against REDRAM, another fallout code using spectral methods developed by Arthur Hopkins (14,15). Overall, the contour patterns produced by the two codes matched very well. Differences between the contour patterns were due to different methods used to calculate g(t) and to the different ways in which the initial stabilized cloud was modeled.

HYDRA uses a finite difference method to calculate g(t), while REDRAM uses a set of coefficients derived from particle fall mechanics data. The method used in HYDRA is more accurate. The particle sizes calculated using the coefficients were smaller than the actual particle sizes, with differences ranging up to six percent. The g(t) calculations were the major source of the differences observed in the contour maps of the two codes.

Different methods are also used to model the initial stabilized cloud. HYDRA models the cloud as a set of pancake clouds, one for each particle size group, with each cloud at a different altitude. REDRAM uses one pancake cloud for all particle size groups. Both models produce nearly identical results for weapon yields between 10 kilotons and 2 megatons. However, outside this range the contour patterns produced by the HYDRA model become progressively wider and shorter compared to those produced by the

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REDRAM model. The HYDRA model is more realistic in that it logically predicts that particles of different sizes will be injected to different altitudes.

Recommendations

1. Determine if data is available for the southern hemisphere. If this data is available, procedures need to be devised for retrieving it.

2. Modify HYDRA so that it can determine dose contours as well as dose rate contours. The needed data item is already present in the code to determine the dose.

3. Hopkins (15) has devised a method to compute the dose rate at arbitrary distances from the burst site. This method should be reviewed for possible inclusion in HYDRA.

4. Develop a set of spectral coefficients for those six nuclear tests used to validate DELFIC and other fallout codes: Johnnie Boy, Jangle-S, Bravo, Small Boy, Koon, and Zuni. This data would be used to further evaluate HYDRA. (15:119)

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Appendix A

Dose Rate Contour Comparisons
HYDRA vs. REDRAM

This appendix contains seven dose rate contour comparisons between HYDRA and REDRAM for Test Cases 1 and 4-9 described in Section IV of this report. HYDRA is the fallout code developed for this project. REDRAM, written by Arthur Hopkins (14,15), is the fallout code that was used to evaluate HYDRA.
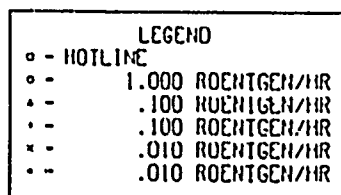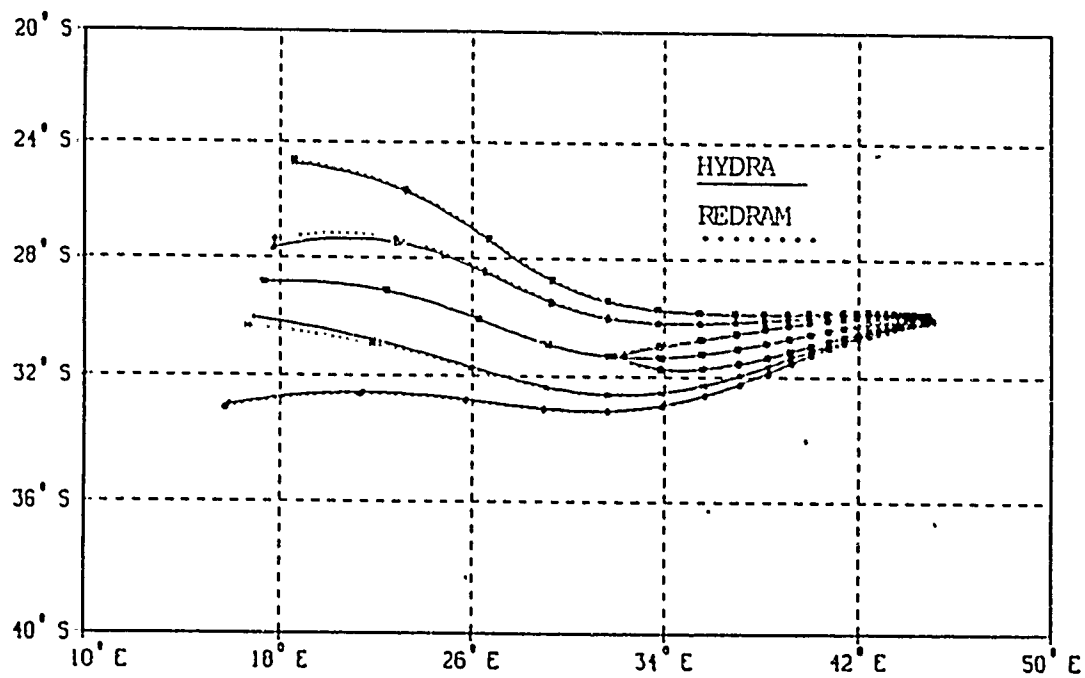
Fig. A-1. Test Case 1: HYDRA vs. REDRAM
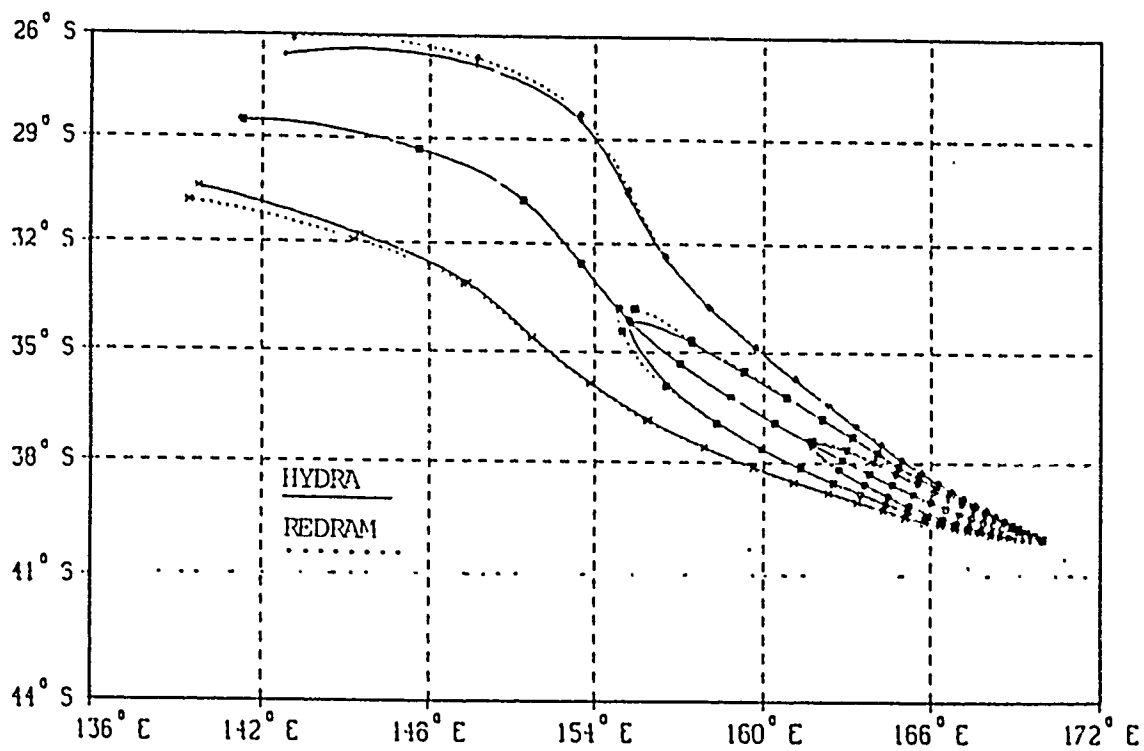
Fig. A-2. Test Case 4: HYDRA vs. REDRAM
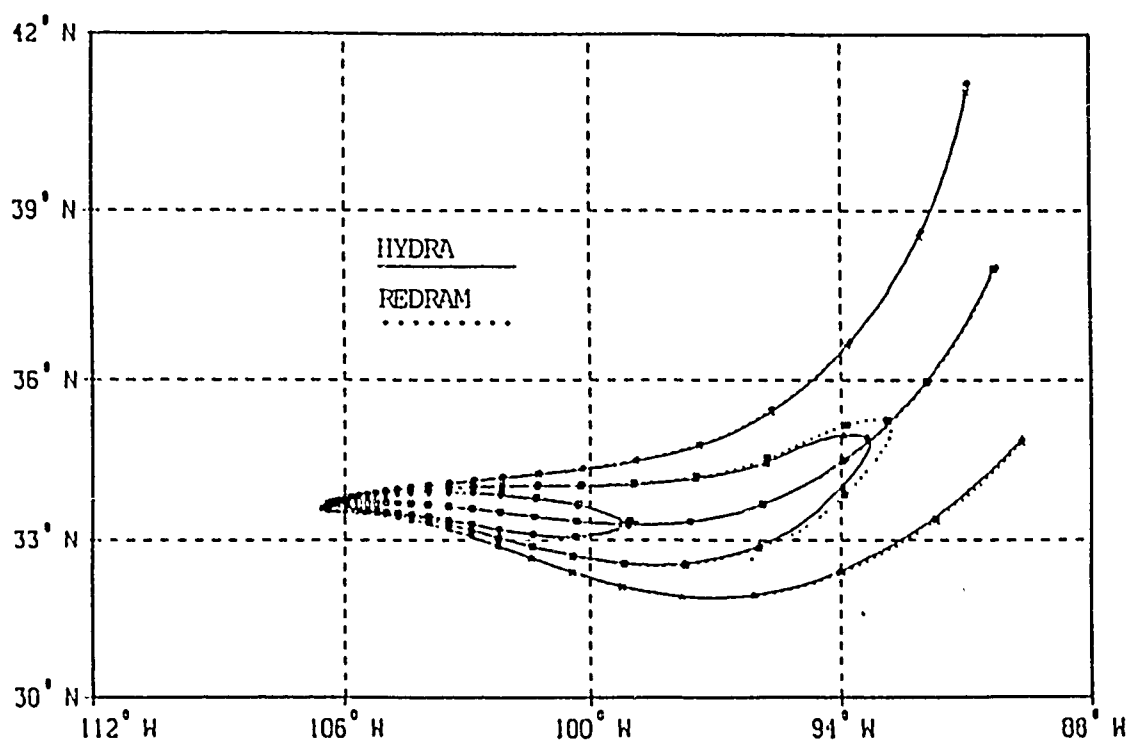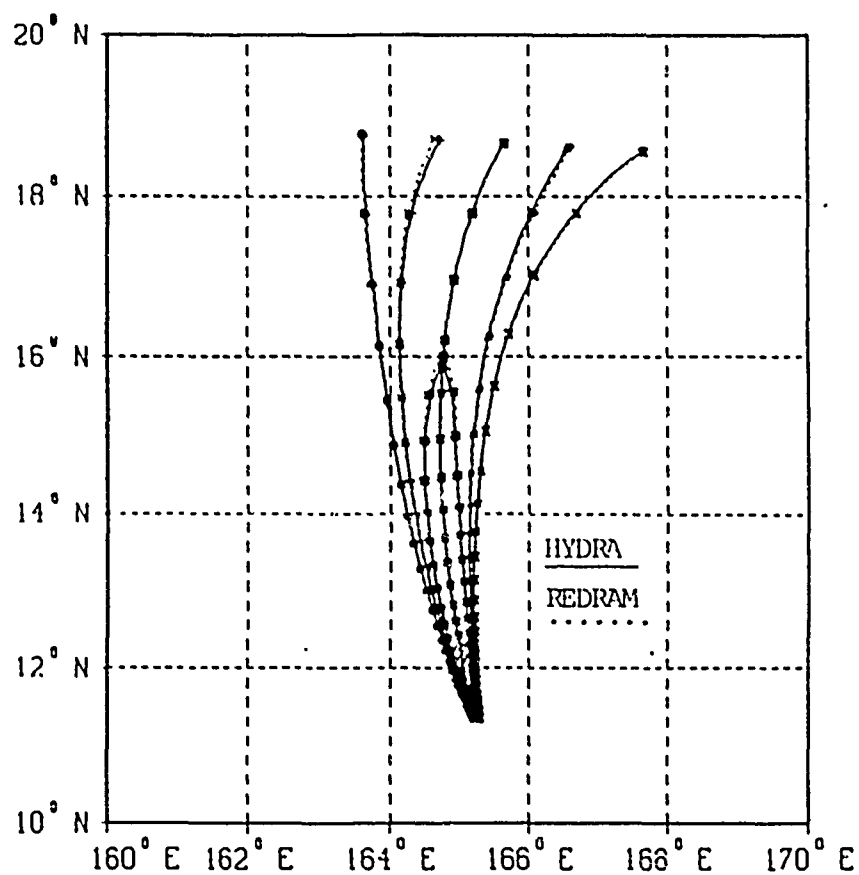
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Legend:

	HYDRA	——
	REDRAM	······

```
            LEGEND
  □ - HOTLINE
  ○ -        1.000 ROENTGEN/HR
  ▲ -         .100 ROENTGEN/HR
  ♦ -         .100 ROENTGEN/HR
  × -         .010 ROENTGEN/HR
  ♦ -         .010 ROENTGEN/HR
```

Fig. A-4.   Test Case 6: HYDRA vs. REDRAM
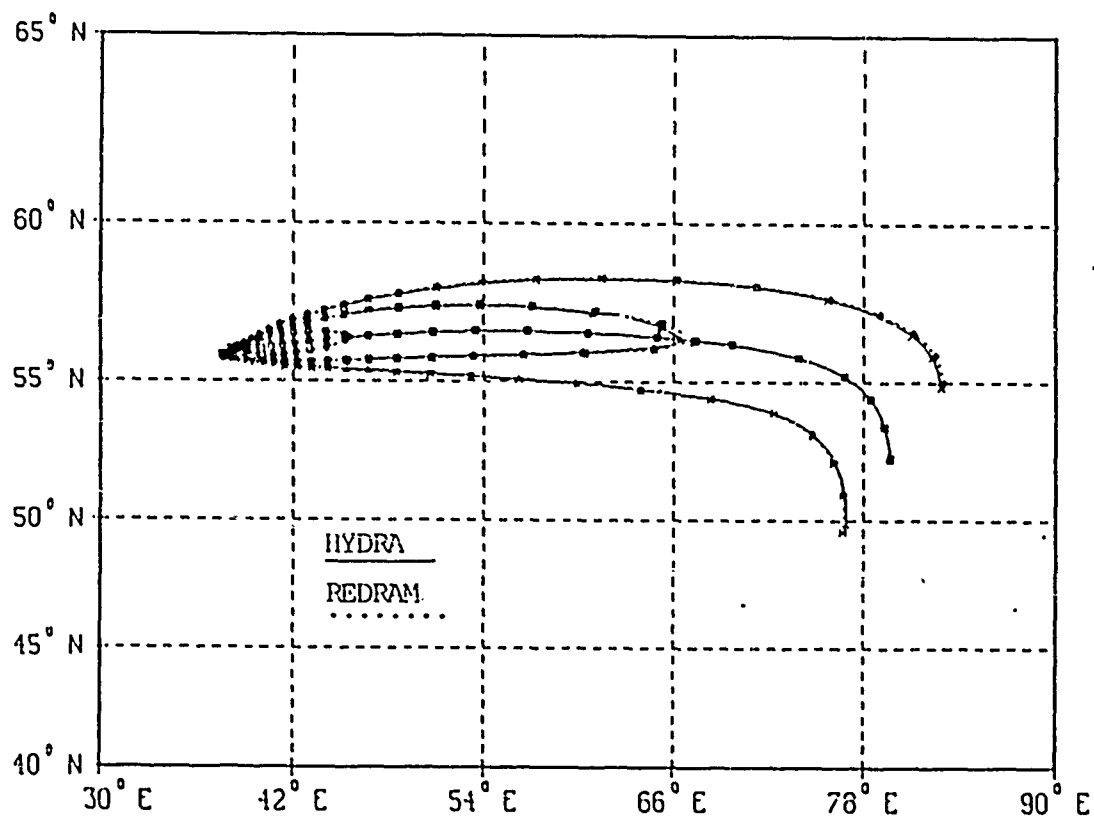
Fig. A-5. Test Case 7: HYDRA vs. REDRAM
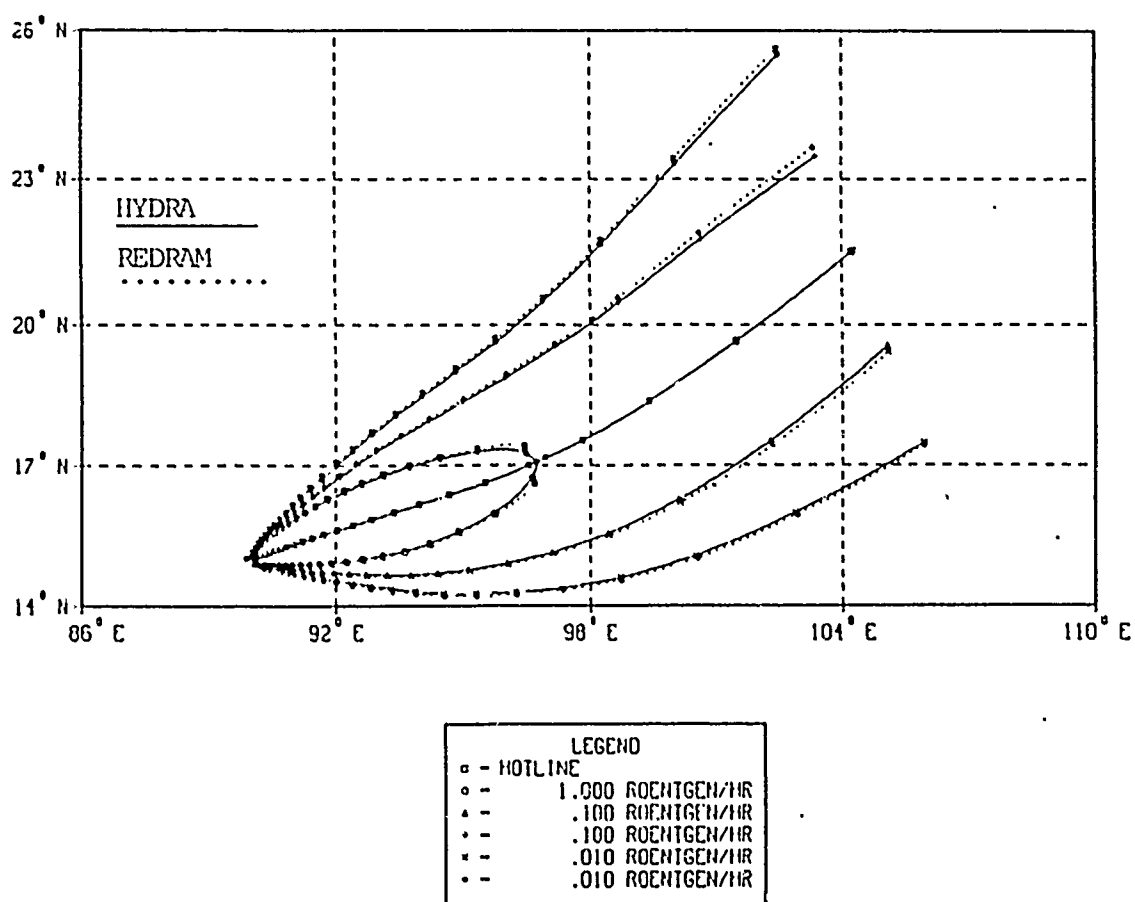
Fig. A-6. Test Case 8: HYDRA vs. REDRAM
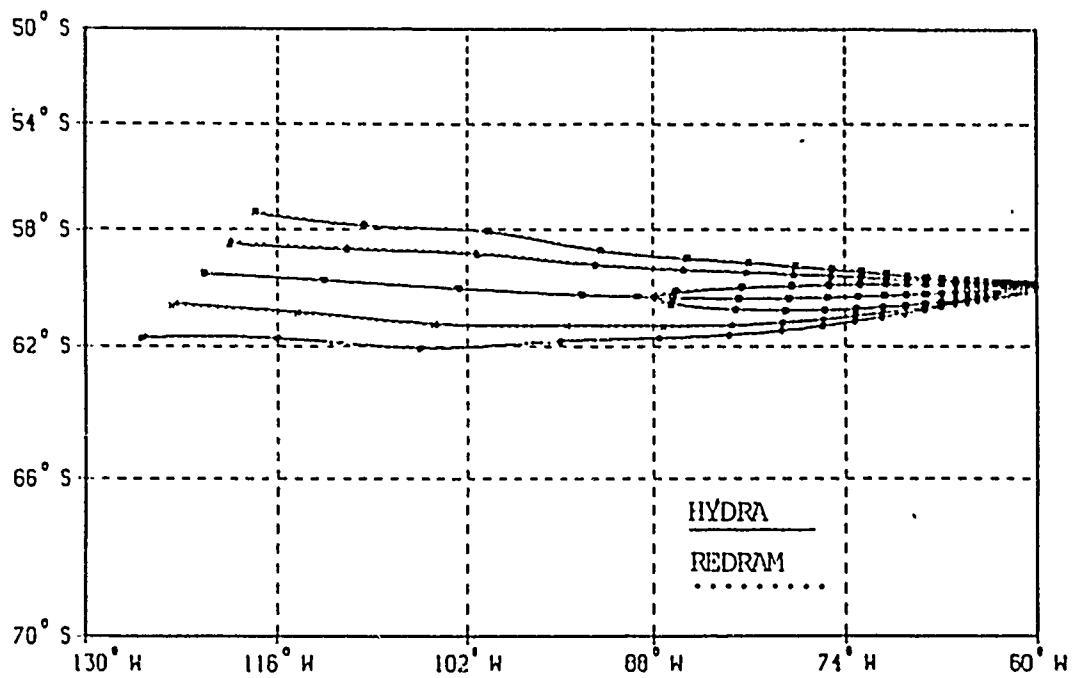
Fig. A-7. Test Case 9: HYDRA vs. REDRAM

Appendix B

Dose Rate Contour Comparisons
Single vs. Multiple Pancake Clouds

This appendix contains nine dose rate contour comparisons between HYDRA and HYDRAS for various yields at the location of Test Case 6. HYDRA uses the multiple pancake cloud method to model the radioactive dust cloud, while HYDRAS uses a single pancake cloud.

HYDRA

HYDRAS ....

22° N

19° N

16° N

13° N

10° N

148° E   154° E   160° E   166° E   172° E
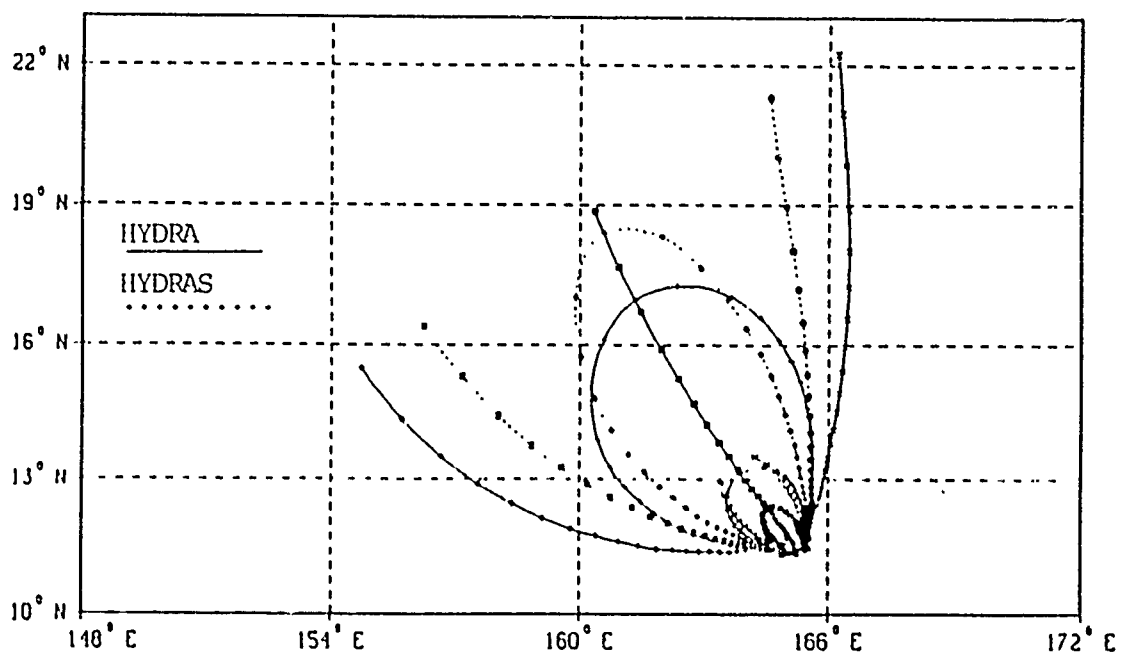
LEGEND
□ – HOTLINE
○ –   500.000 ROENTGEN/HR
▲ –   100.000 ROENTGEN/HR
• –   10.000 ROENTGEN/HR
✗ –   1.000 ROENTGEN/HR
• –   1.000 ROENTGEN/HR

Fig. B-1. HYDRA vs. HYDRAS for a 15 Mt Burst

Fig. B-2. HYDRA vs. HYDRAS for a 10 Mt Burst
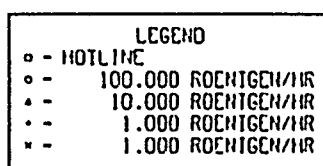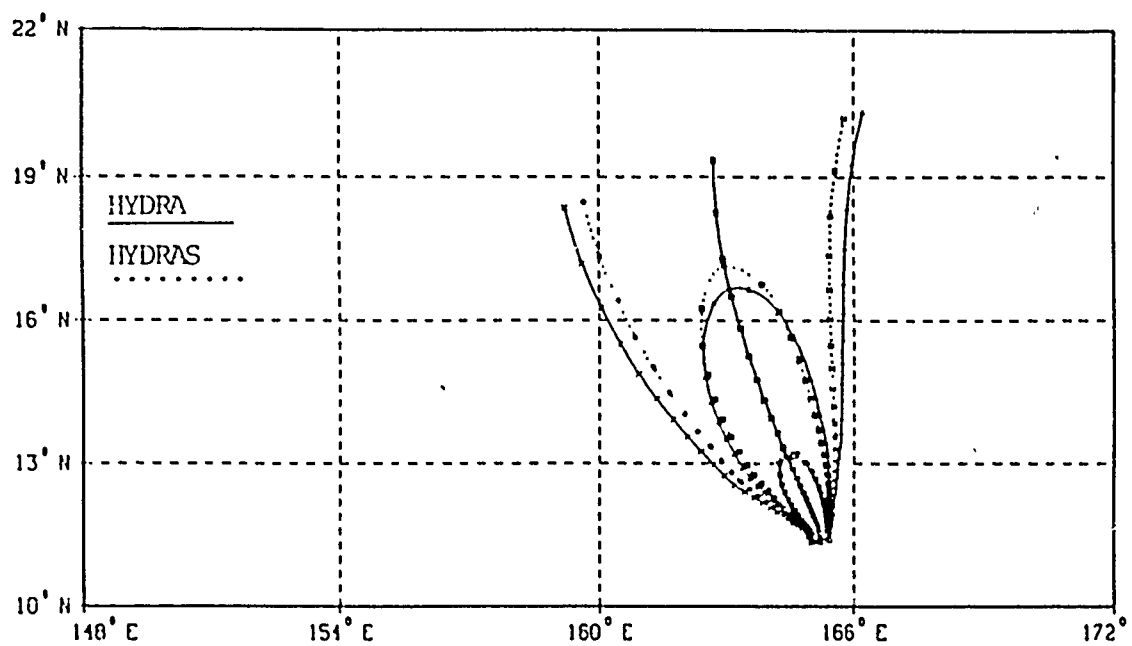
Fig. B-3. HYDRA vs. HYDRAS for a 6 Mt Burst
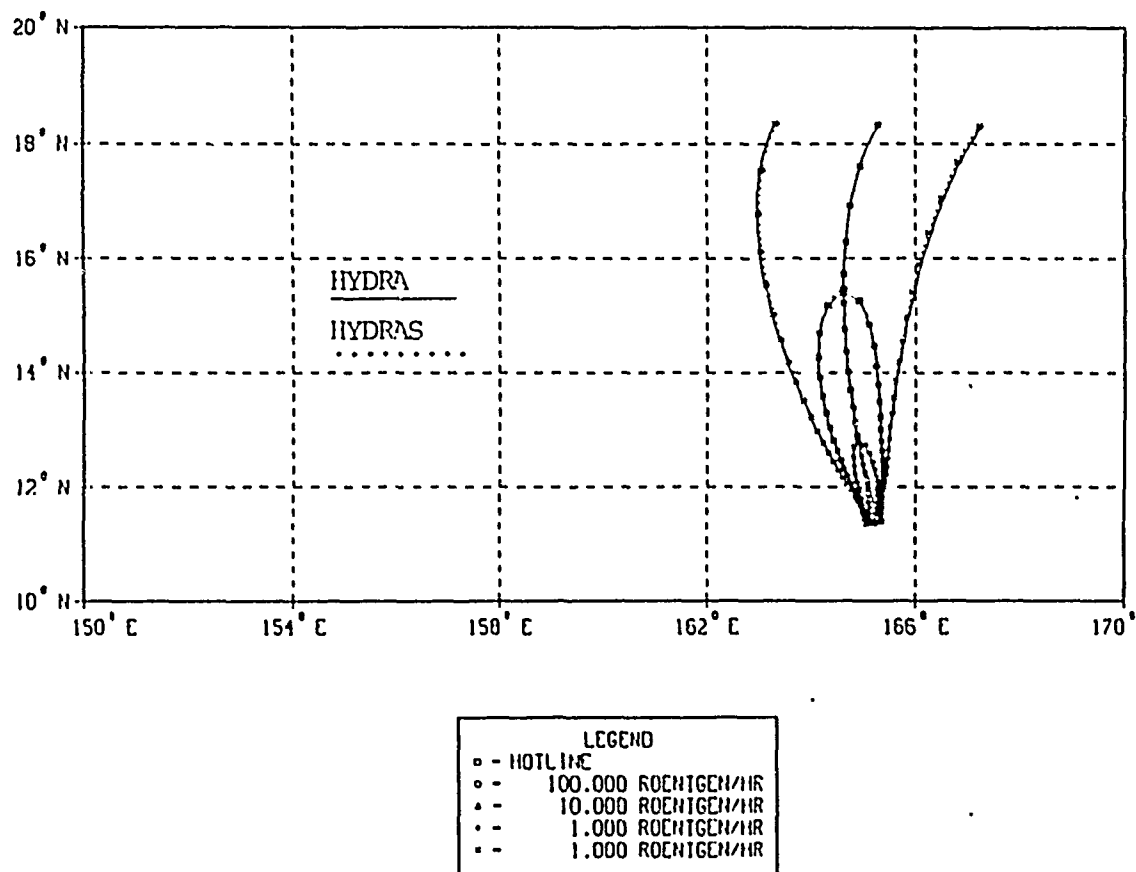
Fig. B-4. HYDRA vs. HYDRAS for a 2 Mt Burst

LEGEND
o - HOTLINE
o -   100.000 ROENTGEN/HR
▲ -   10.000 ROENTGEN/HR
• -   1.000 ROENTGEN/HR
▪ -   1.000 ROENTGEN/HR
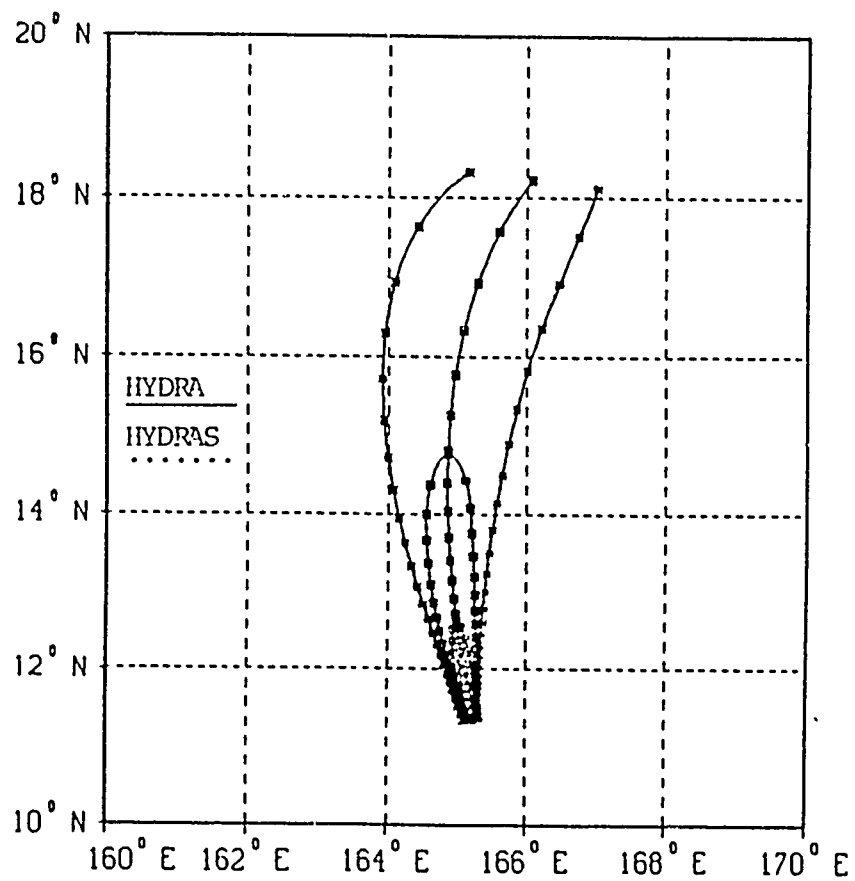
HYDRA
HYDRAS

LEGEND
□ - HOTLINE
○ -   100.000 ROENTGEN/HR
▲ -   10.000 ROENTGEN/HR
+ -   1.000 ROENTGEN/HR
× -   1.000 ROENTGEN/HR

Fig. B-5.   HYDRA vs. HYDRAS for a 1 Mt Burst
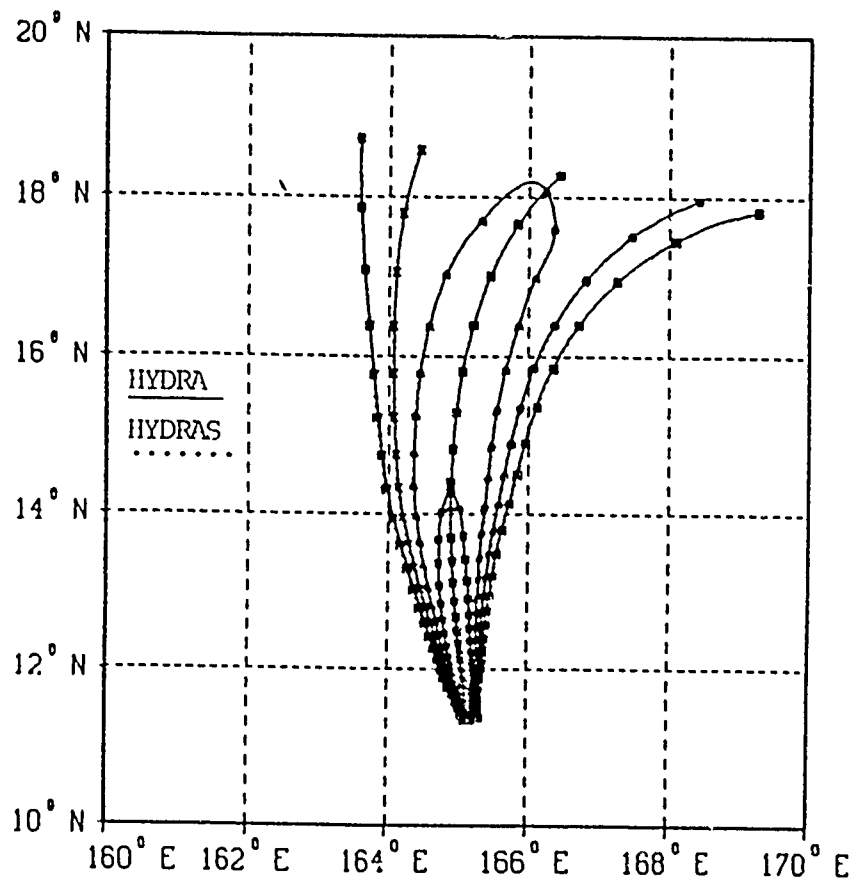
Fig. B-6, HYDRA vs. HYDRAS for a 500 Kt Burst

Fig. B-7. HYDRA vs. HYDRAS for a 100 Kt Burst

LEGEND
□ - HOTLINE
○ -   1.000 ROENTGEN/HR
△ -   .100 ROENTGEN/HR
+ -   .010 ROENTGEN/HR
× -   .010 ROENTGEN/HR

Fig. B-8.   HYDRA vs. HYDRAS for a 10 Kt Burst
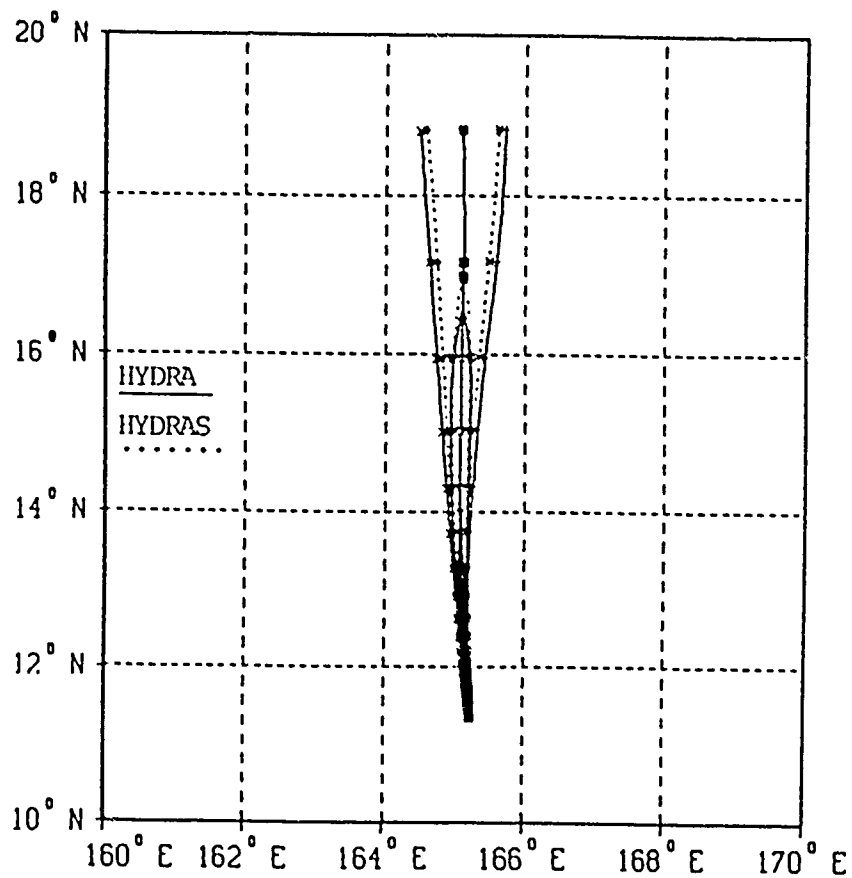
Fig. B-9. HYDRA vs. HYDRAS for a 1 Kt Burst

Appendix C

HYDRA Output With Maps

This appendix contains nine HYDRA dose rate contours overlayed on maps for Test Cases 1 through 9 described in Section IV of this report. The yield in Test Case 6 has been changed from 100 kilotons to 15 megatons. The maps are drawn by the program using DISSPLA software.

DOSE RATE CONTOURS

YIELD (KT) - 500.000   FISSION FRACTION - .500
RMED (MICRONS) - .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - 45.000   LAT(DEG.) - -30.000


```
LEGEND
o - HOTLINE
o -     10.000 ROENTGEN/HR
▲ -      1.000 ROENTGEN/HR
• -       .100 ROENTGEN/HR
• -       .100 ROENTGEN/HR
• -       .010 ROENTGEN/HR
▾ -       .010 ROENTGEN/HR
```
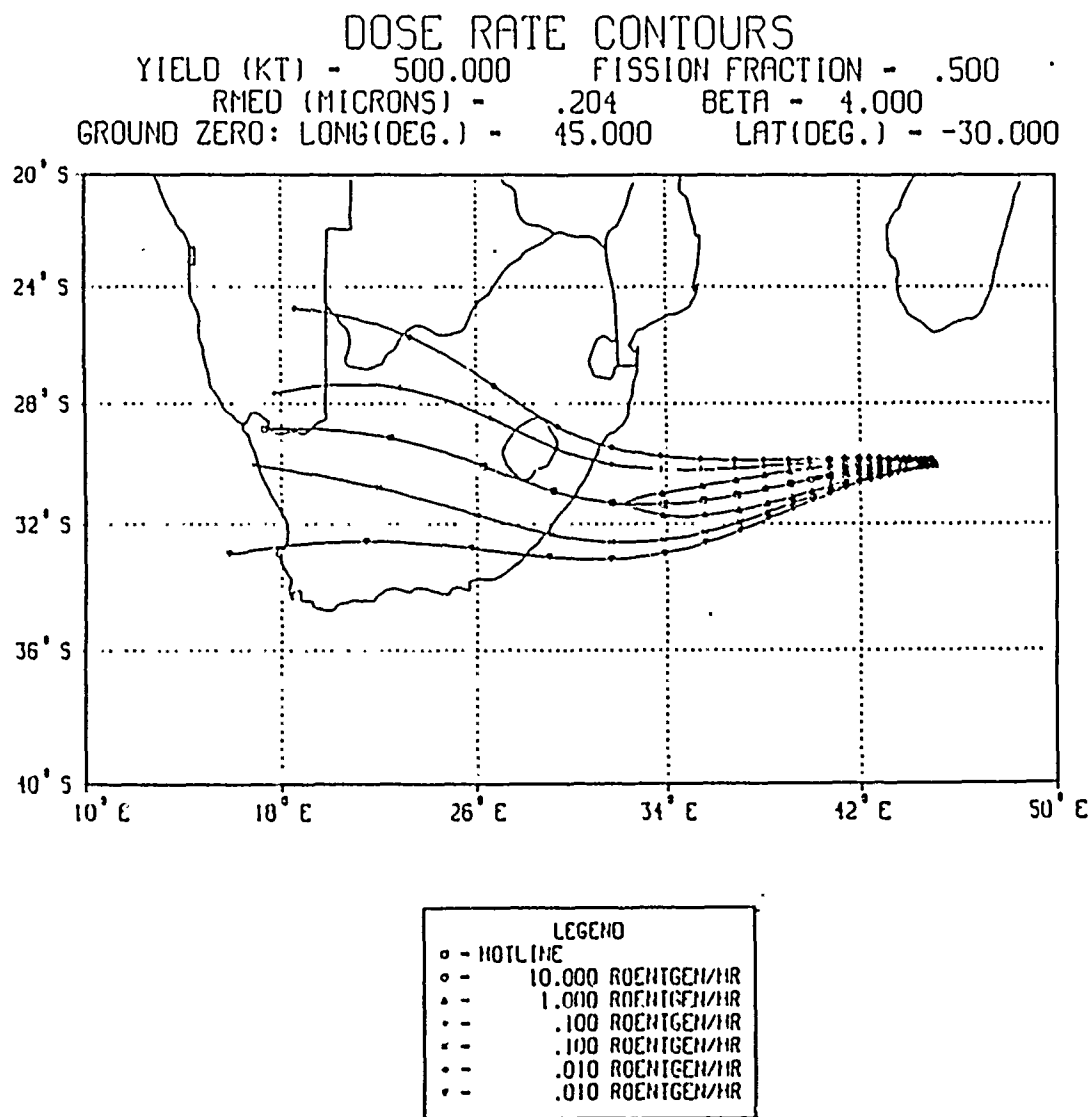
Fig. C-1.   HYDRA Output for Test Case 1

DOSE RATE CONTOURS

YIELD (KT) - 100.000   FISSION FRACTION - .500
RMED (MICRONS) - .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - -6.000   LAT(DEG.) - 46.000

LEGEND
□ - HOTLINE
○ - .500 ROENTGEN/HR
▲ - .100 ROENTGEN/HR
• - .010 ROENTGEN/HR
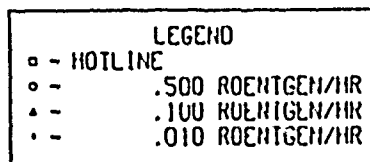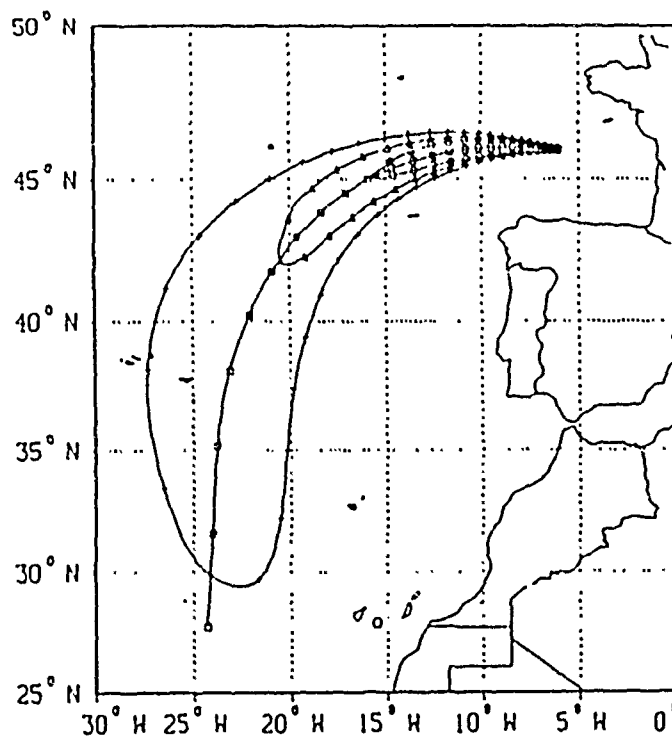
Fig. C-2. HYDRA Output for Test Case 2

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DOSE RATE CONTOURS

YIELD (KT) - 1000.000   FISSION FRACTION - .500
RMED (MICRONS) - .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - 58.000   LAT(DEG.) - 75.000
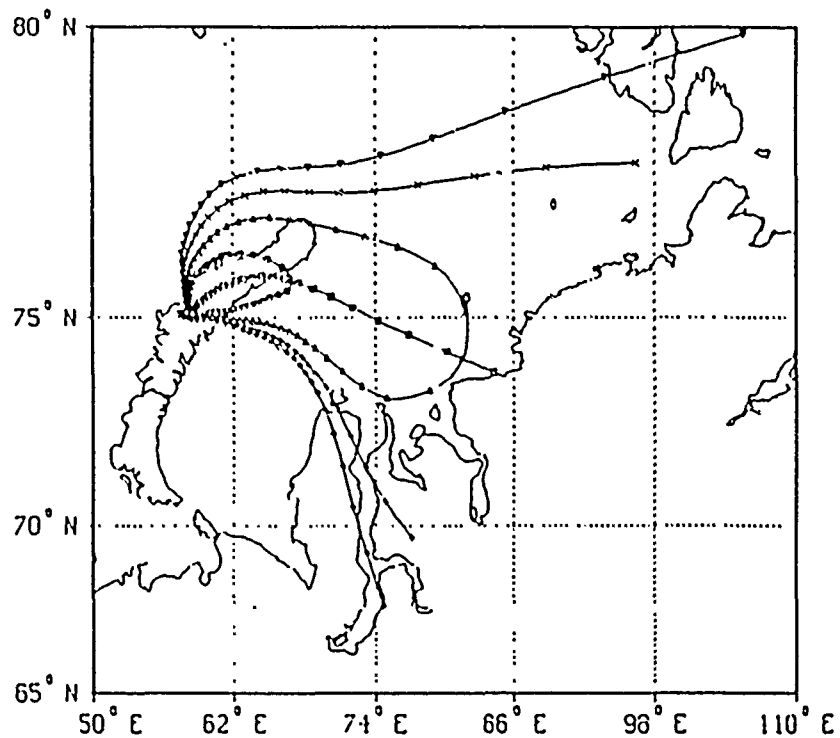
LEGEND	
o -	HOTLINE
o -	10.000 ROENTGEN/HR
▲ -	1.000 ROENTGEN/HR
• -	.100 ROENTGEN/HR
× -	.100 ROENTGEN/HR
• -	.010 ROENTGEN/HR
▼ -	.010 ROENTGEN/HR

Fig. C-3. HYDRA Output for Test Case 3

DOSE RATE CONTOURS

YIELD (KT) - 100.000   FISSION FRACTION - .500
RMED (MICRONS) - .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - 170.000   LAT(DEG.) - -40.000

LEGEND
o - HOTLINE
o - .500 ROENTGEN/HR
▲ - .100 ROENTGEN/HR
ı - .010 ROENTGEN/HR
x - .010 ROENTGEN/HR

Fig. C-4.   HYDRA Output for Test Case 4

DOSE RATE CONTOURS
YIELD (KT) - 100.000   FISSION FRACTION - .500
RMED (MICRONS) - .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - -106.475   LAT(DEG.) - 33.624

LEGEND
□ - HOTLINE
○ -   1.000 ROENTGEN/HR
▲ -   .500 ROENTGEN/HR
• -   .100 ROENTGEN/HR
× -   .010 ROENTGEN/HR
• -   .010 ROENTGEN/HR
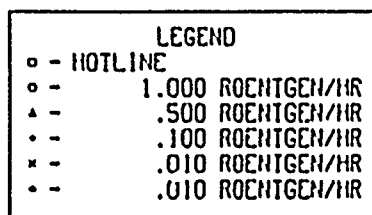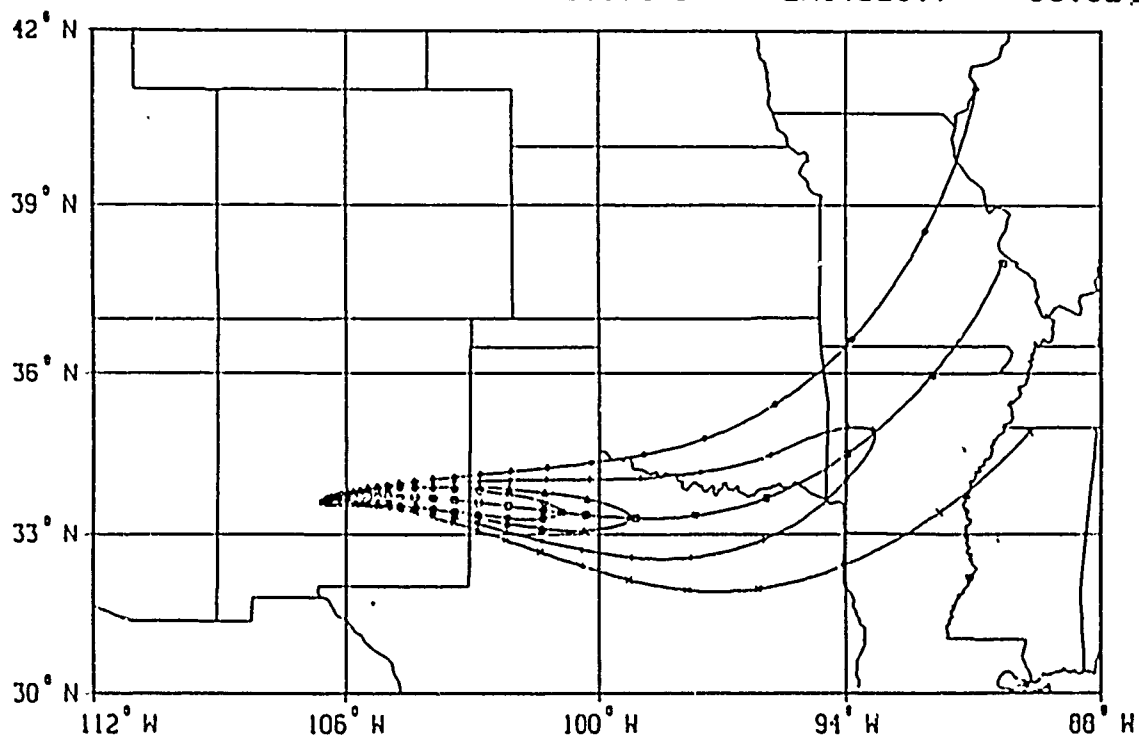
Fig. C-5. HYDRA Output for Test Case 5

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DOSE RATE CONTOURS
YIELD (KT) - 15000.000   FISSION FRACTION - .500
RMED (MICRONS) -   .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - 165.230   LAT(DEG.) - 11.350
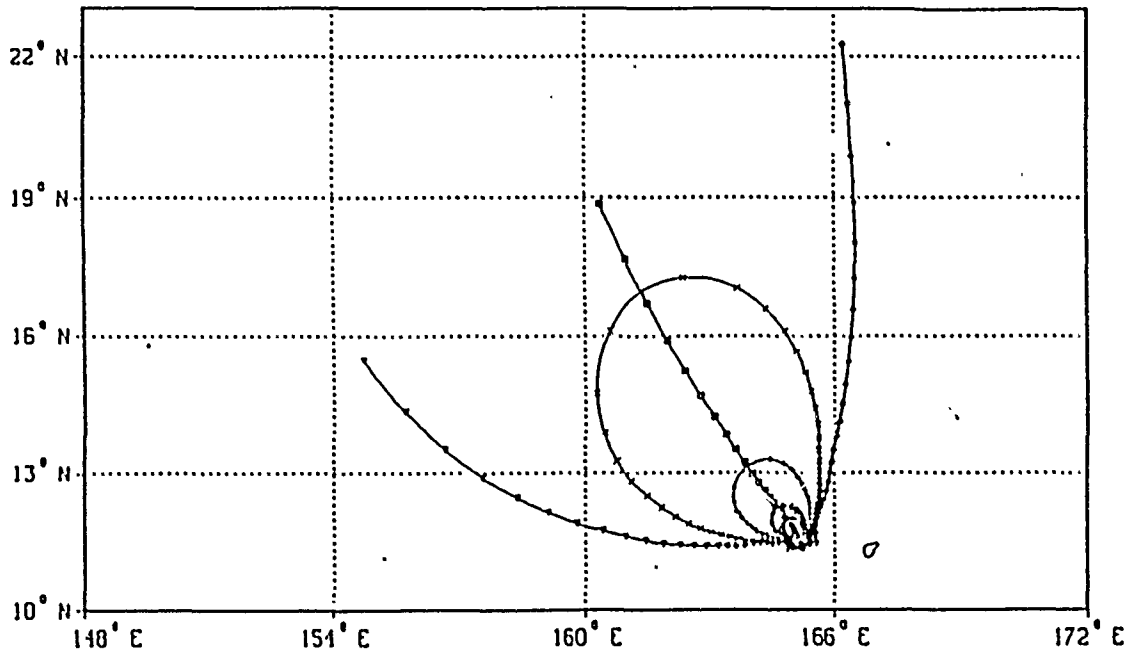
LEGEND
- □ - HOTLINE
- ○ -   1000.000 ROENTGEN/HR
- ▲ -   500.000 ROENTGEN/HR
- ◆ -   100.000 ROENTGEN/HR
- × -   10.000 ROENTGEN/HR
- ◆ -   1.000 ROENTGEN/HR
- ▼ -   1.000 ROENTGEN/HR

Fig. C-6. HYDRA Output for Test Case 6

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DOSE RATE CONTOURS

YIELD (KT) - 1000.000   FISSION FRACTION - .500
RMED (MICRONS) -   .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) -   37.600   LAT(DEG.) - 55.800


```
LEGEND
□ - HOTLINE
○ -      10.000 ROENTGEN/HR
▲ -       1.000 ROENTGEN/HR
• -        .100 ROENTGEN/HR
× -        .100 ROENTGEN/HR
```
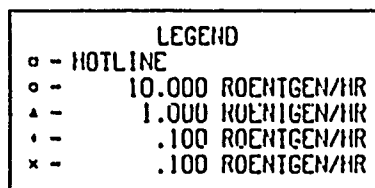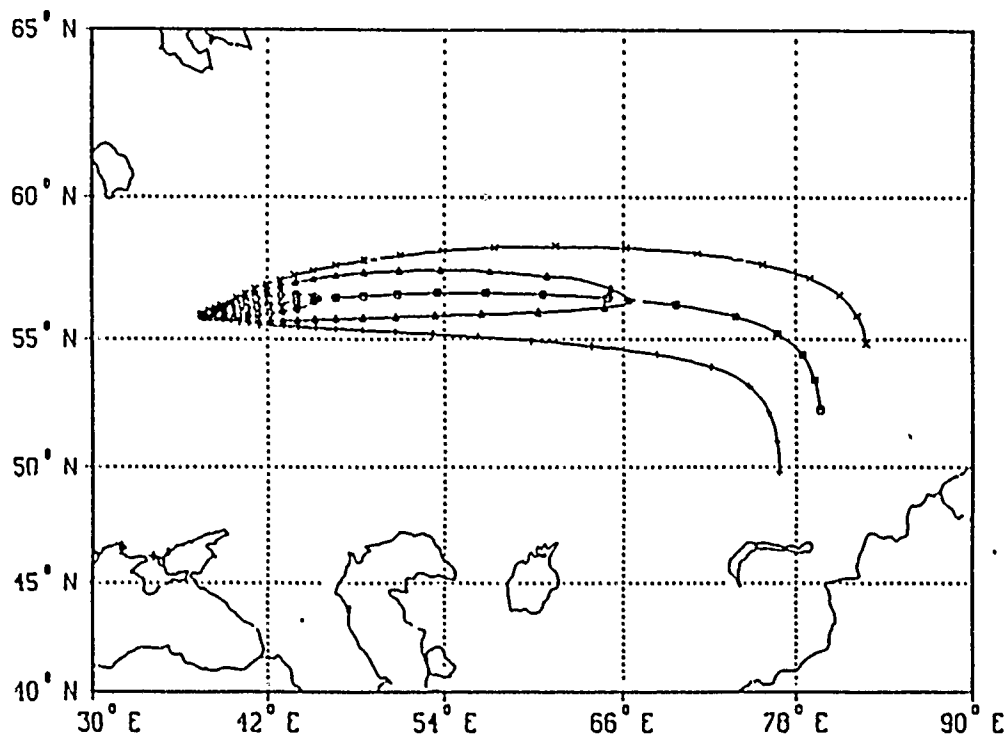
Fig. C-7. HYDRA Output for Test Case 7

DOSE RATE CONTOURS

YIELD (KT) - 500.000   FISSION FRACTION - .500

RMED (MICRONS) - .204   BETA - 4.000

GROUND ZERO: LONG(DEG.) - 90.000   LAT(DEG.) - 15.000

```
LEGEND
□ - HOTLINE
○ -      10.000 ROENTGEN/HR
▲ -       1.000 ROENTGEN/HR
. -        .100 ROENTGEN/HR
× -        .100 ROENTGEN/HR
. -        .010 ROENTGEN/HR
▼ -        .010 ROENTGEN/HR
```

Fig. C-8. HYDRA Output for Test Case 8

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DOSE RATE CONTOURS
YIELD (KT) - 500.000   FISSION FRACTION - .500
RMED (MICRONS) -   .204   BETA - 4.000
GROUND ZERO: LONG(DEG.) - -60.000   LAT(DEG.) - -60.000

LEGEND
□ - HOTLINE
○ -   10.000 ROENTGEN/HR
▲ -   1.000 ROENTGEN/HR
• -   .100 ROENTGEN/HR
▼ -   .100 ROENTGEN/HR
• -   .010 ROENTGEN/HR
▼ -   .010 ROENTGEN/HR
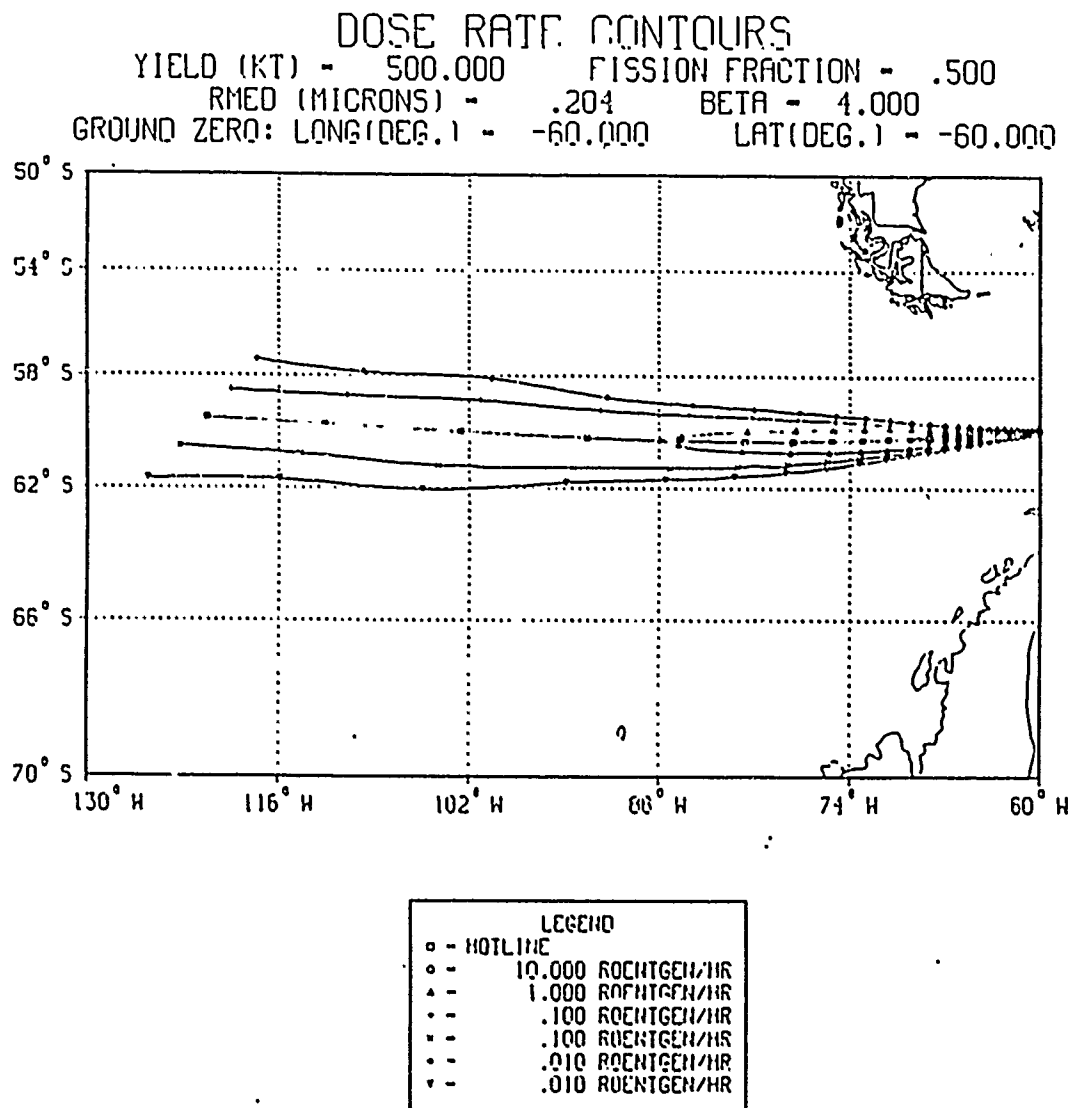
Fig. C-9.   HYDRA Output for Test Case 9

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Appendix D

User's Guide For Operating HYDRA

Introduction

HYDRA is written in Fortran V and is designed to run on the Control Data Corporation (CDC) CYBER 750 computer. The CYBER currently runs version 2.4.2 of the Network Operating System (NOS). The HYDRA codes also use the AFIT procedural file. To get a copy of this file for your CYBER account, enter the following set of commands:

```
GET,PROCFIL/UN=T840115
SAVE,PROCFIL
UPROC,PROCFIL
BEGIN,PV,,XXX
```

here XXX is any three characters you want to appear on the cover page of your printouts. The remainder of this user's guide is divided into the following sections:

1. Compiling HYDRA.

2. Input file descriptions.

3. Running HYDRA.

4. Output file descriptions.

Compiling HYDRA

To compile HYDRA, the HYDRA source file must exist as an indirect access file in your account. The source file is simply called HYDRA. To compile HYDRA, enter the following set of commands:

```
GET,HYDRA
IMSL
FTN5,I=HYDRA,L=0,B=HYDRAB
REPLACE,HYDRAB
RETURN,*
```

These commands will create a compiled version of HYDRA
named HYDRAB. The IMSL command retrieves the IMSL librar-
ies for use by the compiler, and allows the compiler to
recognize the IMSL subroutines used in HYDRA. The RP com-
mand stores HYDRAB as an indirect access file in your
account.

Input File Descriptions

To run HYDRA, the following files are needed as input:

File INITIAL

File INITIAL must exist as an indirect access
file in your account. It consists of a single line
containing the following data (in order):

1. NP - The number of particles used to define
    the hotline. The format is I3. At least 15
    particles should be used. Up to 99 particles
    may be specified, but it is recommended that
    no more than 25 particles be used to keep CPU
    time as low as possible.

The format for each of the remaining data items is
F10.3.

2. YLD - The weapon yield in kilotons. HYDRA
    will be most accurate for yields below 10
    megatons.

3. FF - The fission fraction. FF normally has a
    a value of 0.5.

4. NORCON - The source normalization constant in
    roentgen-km^2/hr-kiloton. One value for this

constant, based on DELFIC data, is 6084.0.

5. RMED – The median particle size in microns of the number-size distribution. The DELFIC default value is 0.204.

6. BETA1 – The natural log of BETA1 is the log slope of the number-size distribution. The DELFIC default value is 4.0.

7. FV – The fraction of the total activity that is distributed in the particle volumes. A typical value for FV is 0.68, which is based on DELFIC data.

8. RHOF – The particle density in kg/m^3. This is normally set to 2600 kg/m^3.

9. DLONO – The longitude of ground zero (GZ) in degrees. DLONO ranges from 0 to 360 degrees.

10. DLATO – The latitude of GZ in degrees. DLATO ranges from -85.0 to 85.0 degrees. Using a value of 90 degrees will cause HYDRA to blow up.

11. TEXIT – The exposure time in hours. This data item is not used at present.

File CONTOUR

File CONTOUR must exist as an indirect access file in your account. This file contains the user-specified contour dose rates in units of roentgens/hr. Any number of dose rates may be specified. Each dose rate value occupies one line. The format for each line is E10.3. The dose rates should be specified in order of decreasing value.

File LEVEL

File LEVEL contains the altitude levels in kilo-meters for the 12 spectral layers. Although the 0.0 altitude level is NOT a spectral layer, it must be

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present for HYDRA to run. There is one altitude per line. The format for each line is F10.3. This file should NEVER be altered in any way. File LEVEL must exist in your account as an indirect access file.

File TAPE72

TAPE72 is the output file from the program AFGL4, and must exist as a direct access file in your account. TAPE72 contains 12 sets of complex spectral coefficients, one set f..r each of the 12 spectral layers. There are three complex pairs of coefficients per line, and the format of each line is 6E13.7. This file should NEVER be altered in any way. The generation of TAPE72 is described in Appendix F.

Running HYDRA

Once the input files have been set up, you are ready to run HYDRA. First, you must modify the AFIT procedural file. This file exists in your account as an indirect access file named PROCFIL. Add the following code to PROCFIL:

```
.PROC,GOHYDRA.
RETURN,*.
GET,HYDRAB,INITIAL,CONTOUR,LEVEL.
ATTACH,SPECOEF=TAPE72.
IMSL.
HYDRAB.
.EOR
.*
```

This code or "proc" should be added immediately after line

number 50. After saving PROCFIL, type:

$$BEGIN,PV,,XXX$$

where XXX is again your cover page designator. This will set up PROCFIL to run the "proc" GOHYDRA.

Type the command GOHYDRA to execute the HYDRA program. After a few seconds, HYDRA will flash the following message on the screen:

```
IF YOU WISH TO USE FORMATTED INPUT, ENTER "0" TO GO ON.
IF YOU WISH TO ENTER DATA FROM THE SCREEN, ENTER "1".
```

Entering "0" next to the program prompt (?) tells HYDRA to use the data from file INITIAL in determining the fallout pattern. Entering a "1" will bypass the INITIAL file and allow you to enter data from the screen instead. Enter one value for each program prompt, and be sure to use decimals.

When HYDRA has completed its calculations, the word STOP will appear on the screen, and the NOS system prompt will appear (/). HYDRA takes approximately 32 CPU seconds to do a 25 particle analysis.

Output File Descriptions

The following files are output from HYDRA:

File DOSERTE

File DOSERTE contains hotline and contour dose rate values and geographic coordinates. There is one set of (X,Y) coordinates per line. The format for each line is 5E12.5, except for the first line, which

is a duplication of the data in file INITIAL with a few additional data items. Each line contains the following data (in order):

1. The X coordinate in kilometers for a hotline or contour point.

2. The Y coordinate in kilometers for a hotline or contour point.

3. Either the user-specified contour dose rate or the calculated dose rate on the hotline in roentgens/hr.

4. Either the calculated contour dose rate (to compare with the user-specified dose rate) or the hotline dose rate in roentgens/hr.

5. The particle radius in microns.

This file should not be modified in any way. It is the file used by the program HYDMAP to map the hotline and contour lines. To save this file for future use by HYDMAP, enter the command:

REPLACE,DOSERTE

after running HYDRA.

File PARTICL

File PARTICL contains a list of the particle sizes calculated by HYDRA in determining the hotline. The particle sizes go in order from smallest to largest. There is one particle size per line. The line format is F10.3. This file is not used by any other program.

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File DIAGNOS

File DIAGNOS contains diagnostic data for each particle size. Some of these variables are $g(t)$, the injection height of the particle, horizontal and verti cal cloud distributions, and shear values. All data items are labeled in DIAGNOS, and the units are specified in the source code.

User's Guide for Operating HYDMAP

Introduction

Like HYDRA, HYDMAP is written in Fortran V and is designed for use on the CDC CYBER 750 computer. The AFIT procedural file is also used by HYDMAP codes. HYDMAP takes the file DOSERTE from HYDRA and plots the coordinates on world maps using DISSPLA software. DOSERTE must exist as an indirect access file on your account for HYDMAP to run. This can be done by typing the command:

REPLACE,DOSERTE

after running HYDRA. A file description of file DOSERTE is given in Appendix D of this report.

Running HYDMAP

To run HYDMAP, the AFIT procedural file (named PROCFIL) must have the following "proc" added to it:

```
.PROC,MAPMAKE.
RETURN,*.
GET,HYDMAP,DOSERTE.
FTN5,I=HYDMAP,L=0.
ATTACH,DISSPLA/UN=APPLIB.
ATTACH,MAPDTA/UN=APPLIB.
LDSET,LIB=DISSPLA,PRESET=ZERO.
LGO.
ATTACH,CCLIB38/UN=LIBRARY.
GET,CALPOP/UN=APPLIB.
LIBRARY,DISSPLA,CCLIB38.
CALPOP,1038,AF,XXX,INPUT,OUTPUT,TAPE99,META.
ROUTE,TAPE99,DC=PU,UN=AF,ST=CSA.
.EOR
.*
```

where XXX is your initials. This "proc" should be inserted after the "proc" GOHYDRA. MAPMAKE automatically retrieves the files and libraries necessary to run HYDMAP, and compiles and executes HYDMAP.

Once the MAPMAKE "proc" has been added to the procedural file, type:

BEGIN,PV,,ZZZ

where ZZZ is the three letter code used to identify your printed output. You are now ready to execute HYDMAP.

To execute HYDMAP, type the single command:

MAPMAKE

This executes the "proc" listed above. After a few seconds, HYDMAP will display the maximum and minimum X and Y coordinates (in degrees) it has calculated for the axes of the plot, along with the grid spacing. HYDMAP then gives you the option of using the values it has calculated or choosing your own values. Enter a "0" after the program prompt (?) to use the calculated values, or a "1" to select your own values.

If you choose to select your own values, HYDMAP will prompt you to set up the axes values and grid spacings, one value at a time. Enter only one value after each program prompt, and be sure to use decimals. The values for the X coordinates must be specified as follows:

1. Western Hemisphere: 0 to -180 degrees.

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2. Eastern Hemisphere: 0 to 180 degrees.

Values for the Y coordinates are specified in a similar manner:

1. Northern Hemisphere: 0 to 85 degrees.
2. Southern Hemisphere: 0 to -85 degrees.

Because HYDMAP uses a Mercator projection to create the maps, a value of 90 or -90 degrees for the Y direction will cause the DISSPLA software to fail. For any plot, the range for the X axis should at least equal the range for the Y axis.

Once the axes and grid spacing values are entered, HYDMAP will display on the screen a set of four-letter codes, each code representing the map of a section of the globe. Choose a map by typing its code next to the program prompt. BE SURE TO ENCLOSE THE CODE IN SINGLE QUOTES OR THE PROGRAM WILL FAIL.

After a map has been chosen and a few seconds have elapsed, some DISSPLA diagnostics will be displayed on the screen. A few more seconds will pass, and the program display the message:

ENTER POST-PROCESSOR DIRECTIVES

along with the program prompt. Simply hit the return key here. The plot is then sent to the HARRIS plotter to be printed. This printing process can take 15 to 20 minutes.

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User's Guide for Creating TAPE72

TAPE72 is the input file to HYDRA which contains the spectral coefficients. To create TAPE72, the following files are needed: ALLWIND, MKTP71, and AFGL4. Each file is described in one of the following sections.

File ALLWIND

File ALLWIND contains gridded wind data for the 12 spectral layers for the following month/days:

1.	14 January 1978	7.	16 July 1981
2.	17 February 1977	8.	28 August 1981
3.	18 March 1981	9.	16 September 1983
4.	11 April 1981	10.	24 October 1983
5.	29 May 1981	11.	6 November 1982
6.	22 June 1980	12.	26 December 1980

This file should never be altered. File ALLWIND, after it has been renamed TAPE40, is the input file to the Fortan program MKTP71. ALLWIND is stored in the Central File System of the Network Operating System (NOS). To retrieve it as a local file named TAPE40, enter the command:

SREAD,TAPE40,ALLWIND,AC1=E840547

File MKTP71

File MKTP71 is a Fortran program that takes the data from ALLWIND as input and outputs the data file TAPE71.

TAPE71 contains gridded wind data for the user-selected month/day in a form which can be read by the Fortran program AFGL4. MKTP71 was written by Lt. Jeff Brown of Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

File AFGL4

File AFGL4 is a Fortran program written in Fortran IV. This code uses the gridded wind data in TAPE71 to create the spectral coefficients stored in TAPE72.

Creating "Proc" MAKE72

To create TAPE72, first insert the following "proc" in the AFIT procedural file, PROCFIL:

```
.PROC,MAKE72.
GET,MKTP71,AFGL4.
FTN5,I=MKTP71,L=0.
LGO.
RETURN,LGO,MKTP71.
REWIND,*.
FTN,I=AFGL4,L=0.
LGO.
PURGE,TAPE72.
REWIND,TAPE72.
COPY,TAPE72,TP72A.
RETURN,TAPE72.
DEFINE,TAPE72.
REWIND,TP72A.
COPY,TP72A,TAPE72.
RETURN,*.
.EOR
.*
```

Add these lines after "proc" MAPMAKE. Once this code has been added, type REPLACE,PROCFIL to store the new version as an indirect access file. Then, type:

BEGIN,PV,,XXX

where XXX is your three-letter output designator. This command updates the procedural file to allow you to run the new "proc" MAKE72. "Proc" MAKE72 compiles and runs MKTP71 and AFGL4.

Creating TAPE72

To create TAPE72, ensure that MKTP71 and AFGL4 are present as indirect access files on your account, and that TAPE40 (ALLWIND) is present as a local file. Then, type the command:

MAKE72

In sequential order, the program will display the month, day, and year for a set of gridded winds. To select a set, type a "1" after the program prompt (?). Only one date may be selected for each run of MAKE72. Type a "2" for those sets you do not wish to use. Then, once MAKE72 has stopped running, the file TAPE72 will exist as a direct access file in your account. You are now ready to run HYDRA.

If a TAPE72 file already exists in your account, it must be renamed if you wish to preserve it. To rename TAPE72, type the following set of commands before running MAKE72:

```
ATTACH,TAPE72
DEFINE,XXXXXXX
COPY,TAPE72,XXXXXXX
RETURN,*
```

where XXXXXXX is the file you wish to store the data in.

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HYDRA Source Code

This appendix contains the HYDRA source code. HYDRA is written in Fortran V and uses two IMSL subroutines, MDNOR and MDNRIS. All physical variables and their units have been defined in the code.

```
C*********************************************************************************
C                        HYDRA - A VARIABLE WIND SMEAR CODE
C
C        HYDRA (HOTLINE YIELD-DEPENDENT RESIDUAL ACTIVITY) FOLLOWS THE PATH
C OF A FALLOUT PARTICLE FROM THE HEIGHT TO WHICH IT IS INJECTED BY A
C NUCLEAR BURST TO ITS FINAL RESTING PLACE ON THE GROUND.  THE DISTANCE
C BETWEEN THE POINT OF BURST AND THE PARTICLE'S LANDING POINT IS DEPENDENT
C ON THE WINDS PRESENT IN THE AREA AND ON THE PARTICLE SIZE.  GIVEN THE
C SAME WINDS, SMALLER PARTICLES WILL LAND FARTHER FROM THE BURST POINT
C THAN WILL LARGER PARTICLES.  THE EFFECTS OF BOTH AND PARTICLE SIZE ARE
C ACCOUNTED FOR IN THIS CODE.
C        THE RATE AT WHICH THE PARTICLE FALLS IS DEPENDENT ON PARTICLE SIZE,
C AND IS CALCULATED USING THE DAVIES-MACDONALD EQUATIONS FOR SPHERICAL
C PARTICLES.  THIS CODE OPERATES ON THE ASSUMPTION THAT ALL PARTICLES ARE
C SPHERICAL.
C        VARIABLE WINDS ARE TAKEN INTO ACCOUNT BY USING THE SPECTRAL COEFFICIENT
C METHOD DEVELOPED BY HOPKINS.  THE ATMOSPHERE IS DIVIDED IN O 12 LAYERS.
C THE WIND DATA IN THIS CODE IS SPLIT INTO X AND Y DIRECTION COMPONENTS.
C IT IS ASSUMED THAT THERE IS NO WIND COMPONENT IN THE Z, OR VERTICAL
C DIRECTION.
C *******************************************************************************
C                  WRITTEN BY CAPT. TONY STRINES, JR. DURING THE PERIOD OCT-DEC 1986.
C *******************************************************************************
C                              VARIABLE DEFINITIONS
C
C   1.  AIRRHO - AIR DENSITY IN KG/M3.
C   2.  AIRVIS - DYNAMIC VISCOSITY OF THE AIR IN KG/M-SEC.
C   3.  BETA1  - LOG(BETA1) = LOGARITHMIC SLOPE OF THE NUMBER-SIZE
C                DISTRIBUTION.  BETA1 = 4.0 FOR DELFIC.
C   4.  CC     - SAME AS COLRAD.
C   5.  CCO    - COLATITUDE OF GROUND ZERO IN RADIANS.
C   6.  CNUM   - NUMBER OF DRATE'S SPECIFIED.
C   7.  COLRAD - CO-LATITUDE OF THE PARTICLE POSITION IN RADIANS.
C   8.  CU     - COMPLEX COEFFICIENT FOR THE X OR LONGITUDINAL WIND
C                COMPONENT IN THE SPECTRAL METHOD.
C   9.  CUMAR  - THE CUMULATIVE ACTIVITY-SIZE DISTRIBUTION.  THE ACTIVITY-
C                SIZE DISTRIBUTION USED IS FREILING'S APPROXIMATION.
C  10.  CV     - COMPLEX COEFFICIENT FOR THE Y OR LATITUDINAL WIND
C                COMPONENT IN THE SPECTRAL METHOD.
C  11.  DELZ   - THICKNESS OF AN ATMOSPHERIC LAYER IN KILOMETERS.
C  12.  DLATO  - LATITUDE OF GROUND ZERO IN DEGREES.  THE EQUATOR
C                CORRESPONDS TO O DEGREES LATITUDE.
C  13.  DLONO  - LONGITUDE OF GROUND ZERO IN DEGREES.  GREENWICH, ENGLAND
C                CORRESPONDS TO O DEGREES LONGITUDE.
C  14.  DRATE  - DESIRED DOSE RATES IN ROENTGENS/HR.  SPECIFIED BY USER FOR
C                THE PURPOSE OF DETERMINING THE DOSE RATE CONTOURS.  MUST
C                BE LISTED IN THE CONTOUR.DATA FILE IN ORDER FROM THE
C                HIGHEST DOSE RATE TO THE LOWEST.
C  15.  DRDT   - TIME RATE OF CHANGE IN THE SIZE OF THE PARTICLES HITTING
C                THE GROUND IN MICRONS/HR.
C  16.  DXKM   - THE DISTANCE IN KILOMETERS TRAVELLED BY A PARTICLE AS IT
C                FALLS THROUGH ONE ATMOSPHERIC LAYER.
C  17.  DYKM   - SAME AS DXKM, BUT IN THE Y DIRECTION.
C  18.  EPS    - EPSILON VALUE USED TO CALCULATE THE ASSOCIATED LEGENDRE
```

```
C                    POLYNOMIALS IN THE SPECTRAL METHOD.
C                         EPS = SQRT((N*N - L*L)/(4*N*N - 1)),
C                    WHERE N IS THE LONGITUDINAL INDEX, AND
C                         L IS THE LATITUDINAL INDEX.
C   19.  FF       - FRACTION OF THE WEAPON YIELD ARISING FROM FISSION
C                    REACTIONS.
C   20.  FV       - FRACTION OF THE ACTIVITY CONTAINED IN THE PARTICLE VOLUME.
C   21.  G        - GRAVITATIONAL CONSTANT IN M/SEC2.
C   22.  HCKF     - HEIGHT IN KILOFEET OF THE FALLOUT CLOUD IN THE PANCAKE
C                    CLOUD APPROXIMATION FROM WSEG-10.
C   23.  HCKM     - SAME AS HCKF EXCEPT IN KILOMETERS.
C   24.  HL       - LOWER BOUND IN KILOMETERS OF THE SPECTRAL LAYER INTO
C                    WHICH THE PARTICLE FALLS.
C   25.  HU       - UPPER BOUND OF THE SPECTRAL LAYER INTO WHICH THE PARTICLE
C                    FALLS.  HU IS IN KILOMETERS.
C   26.  INJHGT   - HEIGHT OF INJECTION IN KILOMETERS FOR A PARTICLE.
C   27.  JCAP     - RHOMBOIDAL TRUNCATION LIMIT FOR THE SPECTRAL METHOD.
C   28.  LCH      - MIDPOINT OF AN ATMOSPHERIC LAYER IN KILOMETERS.
C   29.  LVL      - SPECTRAL LAYER NUMBER, STARTING WITH 1.
C   30.  NEWVX    - X COMPONENT OF THE VELOCITY AT (NEWX,NEWY) OF THE NEW
C                    ALTITUDE IN METERS/SECOND.
C   3'.  NEWVY    - Y COMPONENT OF THE VELOCITY AT (NEWX,NEWY) OF THE NEW
C                    ALTITUDE IN METERS/SECOND.
C   32.  NEWX     - X COORDINATE OF THE PARTICLE AFTER IT HAS FALLEN TO ITS
C                    NEW ALTITUDE.
C   33.  NEWY     - Y COORDINATE OF THE PARTICLE AT THE NEW ALTITUDE.
C   34.  NEWZ     - BOUNDARIES IN KILOMETERS FOR THE ATMOSPHERIC LAYERS.
C   35.  NL       - NUMBER OF ATMOSPHERIC LAYERS INTO WHICH THE ATMOSPHERE IS
C                    DIVIDED.  THE CENTER OF THE HIGHEST LAYER IS THE INJECTION
C                    HEIGHT OF THE PARTICLE.
C   36.  NORCON   - THE SOURCE NORMALIZATION CONSTANT FROM DELFIC.  UNITS ARE
C                    ROENTGEN-KM2/HR-KILOTON.
C   37.  NP       - NUMBER OF PARTICLES CHOSEN TO DETERMINE THE HOTLINE.
C                    GROUND IN 24 HOURS.
C   38.  PRAD     - PARTICLE RADIUS IN MICROMETERS.
C   39.  PROB     - THE VALUE OF THE CUMULATIVE ACTIVITY-SIZE DISTRIBUTION
C                    FOR THE PARTICLE SIZE THAT LANDS AT 24 HOURS (APPROXIMATE).
C   40.  R24      - RADIUS IN MICROMETERS OF THE PARTICLE THAT WILL FALL TO THE
C   41.  RADIUS   - SAME AS RADMIC.
C   42.  RAD      - SAME AS RADMIC.
C   43.  RADLON   - LONGITUDE OF THE PARTICLE POSITION IN RADIANS.
C   44.  RADMIC   - PARTICLE RADIUS IN MICROMETERS.
C   45.  REARTH   - RADIUS OF THE EARTH IN METERS.
C   46.  RHOF     - DENSITY OF THE FALLOUT PARTICLES IN KG/M3.
C   47.  RMED     - PARTICLE RADIUS IN MICROMETERS FOR WHICH HALF OF THE
C                    TOTAL ACTIVITY IS CONTAINED IN PARTICLES HAVING A RADIUS
C                    LESS THAN OR EQUAL TO RMED.  RMED = 0.204 FOR DELFIC.
C   48.  RR       - SAME AS RADLON.
C   49.  RRO      - LONGITUDE OF GROUND ZERO IN RADIANS.
C   50.  SHRX     - SHEAR IN THE X OR LONGITUDINAL DIRECTION IN INVERSE HOURS.
C   51.  SHRY     - SHEAR IN THE Y OR LATITUDINAL DIRECTION IN INVERSE HOURS.
C   52.  SHX      - SHEAR IN THE X OR LONGITUDINAL DIRECTION IN INVERSE
C                    SECONDS FOR A GIVEN ATMOSPHERIC LAYER.
C   53.  SHY      - SHEAR IN THE Y OR LATITUDINAL DIRECTION IN INVERSE SECONDS
```

```
C                    FOR A GIVEN ATMOSPHERIC LAYER.
C   54.   SIZE     - SIZE OF THE INTERVALS ON THAT PORTION OF THE CUMULATIVE
C                    LOGNORMAL ACTIVITY-SIZE DISTRIBUTION WHERE THE PARTICLES
C                    ALL LAND INSIDE OF 24 HOURS.
C   55.   SPCLEV   - ALTITUDE OF A SPECTRAL LEVEL IN KILOMETERS, CORRESPONDING
C                    TO A GIVEN SET OF SPECTRAL COEFFICIENTS.
C   56.   TARRIV   - TIME OF ARRIVAL IN HOURS FOR A PARTICLE ON THE GROUND.
C   57.   TEXIT    - TIME OF EXIT IN HOURS FROM A CONTAMINATED AREA.
C   58.   TFALL    - TIME IN SECONDS FOR A PARTICLE TO FALL THROUGH ONE LAYER.
C   59.   TLAPS    - ELAPSED TIME IN SECONDS SINCE THE BURST.
C   60.   VZ       - VERTICAL VELOCITY OF THE PARTICLE IN M/SEC AT A LAYER
C                    BOUNDARY.
C   61.   XO       - X POSITION OF GROUND ZERO IN KILOMETERS.  X = 0 AT GREEN-
C                    WICH, ENGLAND AND INCREASES AS ONE GOES FROM EAST TO WEST.
C   62.   YO       - Y POSITION OF GROUND ZERO IN KILOMETERS.  Y = 0 AT THE
C                    EQUATOR AND INCREASES AS ONE MOVES NORTH.  Y DECREASES
C                    AS ONE MOVES SOUTH OF THE EQUATOR.
C   63.   YLD      - WEAPON YIELD IN KILOTONS.
C  ****************************************************************************
           PROGRAM HYDRA

           REAL RADMIC, NEWX(0:30), NEWY(0:30), NEWVX(0:30), NEWVY(0:30),
          1 HU, HL, AVEVEL, TEXIT, PRAD, NEWZ, SLOPE, INTCPT, SPCLEV(0:30),
          1 G, YLD, RHOF, NEWVX1, NEWVY1, NEWVX2, NEWVY2, XO, YO, T24,
          1 TARRIV(3), TFALL(0:30), INJHGT(3), LYLD, AIRRHO, AIRVIS, FV,
          1 VZ, VZF(0:30), RAD(3), PI, REARTH, PROB, HCKF, HCKM, LNYMEG, R24,
          1 ALPHO, BETA, CUMAR, SIZE, ALPH25, RADIUS(100), X, TT, HCKM2,
          1 SHRX, SHRY, DELZ, LCH, SHX, SHY, RMED, BETA1, FF, NORCON, DRDT

           INTEGER LVL, JCAP, NL, NP, IER

           PARAMETER (JCAP=30,NL=10)

           COMPLEX CU(12,JCAP+1,JCAP+1), CV(12,JCAP+1,JCAP+1)

           DOUBLE PRECISION COLRAD, RADLON, EPS(JCAP+1,JCAP+1), CCO, RRO

           OPEN (6,FILE='HOTLINE',ERR=100)

C  CALCULATE THE EPSILON COEFFICIENTS.
           CALL EPSLON(JCAP,EPS)

           PI = 3.141593

           REARTH = 6356766.0

           G = 9.81

C  READ IN THE SPECTRAL COEFFICIENT DATA.
           OPEN (5,FILE='SPECOEF',ERR=100)
           REWIND 5
           DO 5 I = 1,12
               READ (5,'(6E13.7,2X)') ((CU(I,N,L),N=1,JCAP+1),L=1,JCAP+1)
               READ (5,'(6E13.7,2X)') ((CV(I,N,L),N=1,JCAP+1),L=1,JCAP+1)
```

```fortran
5       CONTINUE
        CLOSE (5)

C  READ IN THE SPECTRAL LEVEL DATA.
        OPEN (5,FILE='LEVEL',ERR=100)
        DO 30 I = 0,40
            READ (5,'(F10.3)',END=40) SPCLEV(I)
30      CONTINUE
40      CONTINUE
        CLOSE (5)

C  THE USER MAY SPECIFY EITHER FORMATTED OR INTERACTIVE INPUT.
        PRINT *,'IF YOU WISH TO USE FORMATTED INPUT, ENTER "0" TO GO ON.'
        PRINT *,'IF YOU WISH TO ENTER DATA FROM THE SCREEN, ENTER "1".'
        PRINT *,' '

        READ *, IDATA

        IF (IDATA.NE.0) GOTO 6

        OPEN (5,FILE='INITIAL',ERR=100)
        REWIND 5
        READ (5,'(I3,10F10.3)',ERR=100) NP, YLD, FF, NORCON,
     1       RMED, BETA1, FV, RHOF, DLONO, DLATO, TEXIT
        CLOSE (5)

        GOTO 7

6       PRINT *,'ENTER THE YIELD IN KILOTONS:'
        READ *, YLD

        PRINT *, 'ENTER THE FISSION FRACTION:'

        READ *, FF

        PRINT *, 'ENTER THE SOURCE NORMALIZATION CONSTANT (R-KM2/HR-KT):'
        READ *, NORCON

        PRINT *, 'ENTER THE NUMBER OF PARTICLES:'
        READ *, NP

        PRINT *, 'ENTER THE FALLOUT PARTICLE DENSITY IN KG/M3:'
        READ *, RHOF

        PRINT *, 'ENTER THE MEDIAN PARTICLE SIZE IN MICRONS:'
        READ *, RMED

        PRINT *, 'ENTER SLOPE OF THE NUMBER-SIZE DISTRIBUTION:'
        READ *, BETA1

        PRINT *, 'ENTER THE ACTIVITY-VOLUME FRACTION:'
        READ *, FV

        PRINT *, 'ENTER THE LONGITUDE IN DEGREES OF GROUND ZERO:'
```

110

```
                READ *, DLONO

                PRINT *, 'ENTER THE LATITUDE IN DEGREES OF GROUND ZERO:'
                READ *, DLATO

                PRINT *, 'ENTER THE EXIT TIME FROM THE AREA IN HOURS:'
                READ *, TEXIT

      7         IF (DLATO.GE.0.0) THEN
                    COLRAD = PI/2.0 - DLATO*PI/180.0
                ELSE
                    COLRAD = -PI/2.0 - DLATO*PI/180.0
                ENDIF
                CCO = COLRAD
                RADLON = DLONO * PI / 180.0
                RRO = RADLON
                YO = COLRAD * REARTH / 1000.0
                XO = RADLON * REARTH * DSIN(COLRAD) / 1000.0

                WRITE (6,'(14F10.3)') YLD, FV, RMED, BETA1, RHOF,
              1     DLONO, DLATO, RRO, CCO, XO, YO, TEXIT, FF, NORCON



      C   FIND THE DESIRED NUMBER OF PARTICLES THAT WILL ALL STRIKE THE GROUND
      C   INSIDE OF 24 HOURS.  FIRST, CALCULATE THE HEIGHT OF THE PANCAKE CLOUD
      C   USING THE WSEG-10 FORMULA.
                OPEN (8,FILE='PARTICL',ERR=100)

                LNYMEG = LOG(YLD/1000.0)
                HCKF = 44.0 + 6.1*LNYMEG - .205*(LNYMEG+2.42)*ABS(LNYMEG+2.42)
                HCKM = (1.609/5.28) * HCKF
                HCKM2 = HCKM / 2.0

      C   ESTIMATE THE SIZE OF THE PARTICLE THAT WILL HIT THE GROUND AT EXACTLY
      C   24 HOURS USING MCDONALD-DAVIES FALL MECHANICS.
                CALL STDATM(HCKM2,AIRRHO,AIRVIS)
                R24 = 5.0
      12        CALL VFALL(AIRRHO,RHOF,R24,AIRVIS,VZ)
                T24 = (HCKM*1000.0) / (VZ*3600.0)
                IF (T24.LT.24.0) GOTO 15
                R24 = R24 + 1.0
                GOTO 12
      15        R24 = R24 - 1.0

      C   SUBROUTINE MDNOR IS AN IMSL ROUTINE THAT CALCULATES THE CUMULATIVE
      C   PROBABILITY OF A GAUSSIAN FUNCTION AT A SPECIFIED VALUE OF THE
      C   DEPENDENT VARIABLE (LT IN THIS CASE).
                ALPHO = LOG(RMED)
                BETA = LOG(BETA1)

      C   THIS IS FREILING'S APPROXIMATION OF THE FRACTIONATED ACTIVITY-SIZE
      C   DISTRIBUTION.
                ALPH25 = ALPHO + 2.5 * BETA**2.0
```

111

```
          TT = (LOG(R24) - ALPH25) / BETA
          CALL MDNOR (TT,PROB)
          SIZE = (1.0 - PROB) / NP

          CUMAR = PROB + SIZE/2.0

C  SUBROUTINE MDNRIS CALCULATES THE VALUE OF THE DEPENEDENT VARIABLE (X
C  IN THIS CASE) OF A NORMAL GAUSSIAN DISTRIBUTION GIVEN THE VALUE OF
C  THE CUMULATIVE PROBABILITY OF THE GAUSSIAN (CUMAR).  MDNRIS IS AN
C  IMSL SUBROUTINE.
          DO 10 I = 1,NP
              CALL MDNRIS (CUMAR,X,IER)
              RADIUS(I) = EXP(X*BETA + ALPH25)
              WRITE (8,'(F10.3)') RADIUS(I)
              CUMAR = CUMAR + SIZE
10      CONTINUE

          CLOSE (8)




C  CALCULATE THE TIME OF ARRIVAL, THE FINAL POSITION ON THE GROUND, AND
C  THE SHEAR FORCES FOR EACH PARTICLE SIZE.
          OPEN (5,FILE='PARTICL',ERR=100)
          REWIND 5
45      READ (5,'(F10.3)',END=90) RADMIC

          RAD(1) = RADMIC - RADMIC*0.01
          RAD(2) = RADMIC + RADMIC*0.01
          RAD(3) = RADMIC

          DO 75 K = 1,3

C         CALCULATE THE TIME OF ARRIVAL FOR EACH PARTICLE.
              PRAD = RAD(K)
              CALL ARRTIM(YLD,PRAD,NL,RHOF,DELZ,TA,PINJHT,TFALL)
              TARRIV(K) = TA
              INJHGT(K) = PINJHT

              IF (K.NE.3) GOTO 75

C         FIND THE NEW X, Y, AND Z COORDINATES OF THE PARTICLE AT EACH LEVEL.
              NEWX(NL+1) = 0.0
              NEWY(NL+1) = 0.0
              SHRX = 0.0
              SHRY = 0.0
              TLAPS = 0.0
              COLRAD = CCO
              RADLON = RRO

              DO 70 I = NL, 1, -1
                  TLAPS = TLAPS + TFALL(I)
                  NEWZ = I * DELZ
                  LCH = NEWZ - (0.5*DELZ)
```

112

```
C                  CALCULATE THE AVERAGE WIND VELOCITY ENCOUNTERED BY EACH
C                  PARTICLE IN EACH ATMOSPHERIC LAYER.
                   CALL LAYERS(LCH,SPCLEV,LVL,HU,HL)
                   IF (LVL.EQ.1) THEN
                       CALL UVCOMP(COLRAD,RADLON,LVL,EPS,CU,CV,NEWVX2,NEWVY2)
                       NEWVX1 = 0.0
                       NEWVY1 = 0.0
                       GOTO 81
                   ENDIF
                   IF (LVL.EQ.13) THEN
                       LVL = 12
                       CALL UVCOMP(COLRAD,RADLON,LVL,EPS,CU,CV,NEWVX1,NEWVY1)
                       NEWVX(I) = NEWVX1
                       NEWVY(I) = NEWVY1
                       GOTO 83
                   ENDIF
                   CALL UVCOMP(COLRAD,RADLON,LVL,EPS,CU,CV,NEWVX2,NEWVY2)
                   LVL = LVL - 1
                   CALL UVCOMP(COLRAD,RADLON,LVL,EPS,CU,CV,NEWVX1,NEWVY1)

81                 NEWVX(I) = (NEWVX2-NEWVX1) * (LCH-HL) / (HU-HL) + NEWVX1
                   NEWVY(I) = (NEWVY2-NEWVY1) * (LCH-HL) / (HU-HL) + NEWVY1

83                 IF (I.EQ.NL) GOTO 66

C                  CALCULATE THE ROOT-MEAN-SQUARE SHEAR IN THE X AND Y DIRECTIONS.
                   SHRX = SHRX + ((NEWVX(I+1) - NEWVX(I))/(DELZ*1000.0))**2.0
     1                       * TFALL(I+1)
                   SHX = SQRT(SHRX / TLAPS)
                   SHRY = SHRY + ((NEWVY(I+1) - NEWVY(I))/(DELZ*1000.0))**2.0
     1                       * TFALL(I+1)
                   SHY = SQRT(SHRY / TLAPS)

66                 CONTINUE

                   DXKM = NEWVX(I) * TFALL(I) / 1000.0
                   NEWX(I) = NEWX(I+1) + DXKM

                   DYKM = NEWVY(I) * TFALL(I) / 1000.0
                   NEWY(I) = NEWY(I+1) + DYKM

                   COLRAD = COLRAD - DYKM * 1000.0 / REARTH
                   RADLON = RADLON + DXKM * 1000.0
     1                               / (REARTH * DSIN(COLRAD))

70        CONTINUE

75      CONTINUE

        DRDT = ABS( (RAD(1) - RAD(2)) / (TARRIV(1) - TARRIV(2)) )

C  CALCULATE THE TOTAL SHEAR ENCOUNTERED BY THE PARTICLE AS IT FALLS FROM
C  ITS INJECTION HEIGHT TO THE GROUND.
```

113

```fortran
      SIIRX = SQRT(SIIRX*3600.0/TARRIV(3))
      SIIRY = SQRT(SIIRY*3600.0/TARRIV(3))

      WRITE (6,912) RADMIC, NEWX(1), NEWY(1),
     1      COLRAD, RADLON, SIIRX, SIIRY, DRDT, INJHGT(3), TARRIV(3)
912   FORMAT (10E12.6)

      GOTO 45

90    CLOSE (5)
      CLOSE (6)

C  CALCULATE THE ACTIVITY ALONG THE HOTLINE AND ALONG THE GAUSSIANS
C  EXTENDING FROM THE HOTLINE.
      CALL ACTVTY

100   STOP
      END
```

```
C ***********!******************************************************
C                        SUBROUTINE ARRTIM
C
C       THIS SUBROUTINE CALCULATES THE TIME OF ARRIVAL IN HOURS FOR A
C FALLOUT PARTICLE OF ANY SIZE.
C ****************************************************************************
C                        VARIABLE DEFINITIONS
C
C   1.   ALT     - THE ALTITUDE IN KILOMETERS AT AN ATMOSPHERIC LAYER
C                    BOUNDARY.
C   2.   AVEVEL  - AVERAGE FALL VELOCITY IN METERS/SEC FOR A PARTICLE
C                    IN A GIVEN ATMOSPHERIC LAYER.  IT IS SIMPLY THE
C                    AVERAGE OF THE VELOCITIES AT THE LAYER BOUNDARIES.
C   3.   INTCPT  - INTERCEPT FOR HOPKIN'S EMPIRICAL FITS.  UNITS OF METERS.
C                    (SEE DTIC #A115-514).
C   4.   PINJHT  - HEIGHT OF INJECTION IN KILOMETERS FOR A PARTICLE.
C   5.   SLOPE   - SLOPE FOR HOPKIN'S EMPIRICAL FITS OF INJECTION HEIGHT
C                    AS A FUNCTION OF PARTICLE SIZE.  UNITS OF
C                    METERS/MICROMETERS.
C   6.   TA      - TIME OF ARRIVAL ON THE GROUND IN HOURS FOR A PARTICLE.
C   7.   TFALL   - FALL TIME FOR A PARTICLE IN A GIVEN ATMOSPHERIC LAYER
C                    IN SECONDS.
C   8.   VZF     - PARTICLE FALL VELOCITY IN METERS/SEC.
C ****************************************************************************
      SUBROUTINE ARRTIM(YLD,PRAD,NL,RHOF,DELZ,TA,PINJHT,TFALL)

      REAL LYLD, INTCPT, NEWZ, VZF(0:30), TFALL(0:30)

      INTEGER NL

C CALCULATE THE INJECTION HEIGHT OF THE PARTICLE USING HOPKIN'S
C EMPIRICAL FITS.
      LYLD = LOG(YLD)
      SLOPE = -EXP(1.574 - .01197*LYLD + .03636*(LYLD**2.0)
     1          - .0041*(LYLD**3.0) + .0001965*(LYLD**4.0))
      INTCPT = EXP(7.889 + .34*LYLD + .001226*(LYLD**2.0)
     1          - .005227*(LYLD**3.0) + .000417*(LYLD**4.0))
      PINJHT = (SLOPE * 2.0 * PRAD + INTCPT) / 1000.0

C HOPKIN'S FITS CAN PRODUCE NEGATIVE INJECTION HEIGHTS FOR LARGE
C PARTICLES (> 500 MICRONS) AND LOW YIELDS (< 10 KT), SO THIS SIMPLE
C FIX WAS ADDED TO INSURE THAT INJECTION HEIGHTS ARE ALWAYS POSITIVE.
      IF (PINJHT.LT.0.0) PINJHT = OLDINJ * OLDRAD / PRAD
      NEWZ = PINJHT

C CALCULATE THE LAYER THICKNESS.  THE ATMOSPHERE IS DIVIDED INTO 10
C LAYERS WITH THE TOP OF THE HIGHEST LAYER BEING THE PARTICLE INJECTION
C HEIGHT.
      DELZ = NEWZ / (NL - 0.5)
      NEWZ = NEWZ + (0.5 * DELZ)

C CALCULATE THE AIR DENSITY AND THE DYNAMIC VISCOSITY AT EACH ALTITUDE
C LEVEL (SUBROUTINE STDATM).
```

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```fortran
C   CALCULATE THE REYNOLDS NUMBER AND THE PARTICLE'S FALL VELOCITY AT
C   EACH ALTITUDE LEVEL (SUBROUTINE VFALL).
          DO 50 I = NL, 0, -1
              ALT = I * DELZ
              CALL STDATM(ALT,AIRRHO,AIRVIS)
              CALL VFALL(AIRRHO,RHOF,PRAD,AIRVIS,VZ)
              VZF(I) = VZ
50        CONTINUE

C   CALCULATE THE AMOUNT OF TIME IT TAKES THE PARTICLE TO FALL THROUGH
C   EACH LEVEL.
          TA = 0.0
          DO 60 I = NL, 1, -1
              AVEVEL = (VZF(I) + VZF(I-1)) / 2.0
              TFALL(I) = 1000.0 * DELZ / AVEVEL
              TA = TA + TFALL(I)/3600.0
60        CONTINUE

          OLDINJ = PINJHT
          OLDRAD = PRAD

          END
```

```fortran
C *************************************************************************
C                         SUBROUTINE STDATM
C
C    THIS SUBROUTINE USES THE US STANDARD ATMOSPHERE TO CALCULATE THE AIR
C  DENSITY AND DYNAMIC VISCOSITY AT ALTITUDES RANGING FROM 0 TO 61,000
C  METERS.
C *************************************************************************
C                         VARIABLE DEFINITIONS
C
C  1.  AIRRHO - AIR DENSITY IN KG/M3 FOR A GIVEN ALTITUDE.
C  2.  AIRVIS - DYNAMIC VISCOSITY OF AIR IN KG/M-S FOR A GIVEN ALTITUDE.
C  3.  ALT    - ALTITUDE IN METERS.
C  4.  T      - TEMPERATURE IN DEG. K AT ALT.
C  5.  P      - PRESSURE IN PASCALS AT ALT.
C  6.  PO     - PRESSURE IN PASCALS AT SEA LEVEL.
C *************************************************************************

      SUBROUTINE STDATM(NEWZ,AIRRHO,AIRVIS)

      REAL NEWZ, AIRRHO, AIRVIS, P, T, PO, ALT

      PO = 1.013E+05

      ALT = NEWZ * 1000.0

      T = 0.0
      P = 0.0

      IF (ALT.LT.11000.0) THEN
         T = 288.15 - 0.006545*ALT
         P = PO * (288.15/T)**(-.034164/.006545)
         GOTO 100
      ENDIF

      IF (ALT.GE.11000.0 .AND. ALT.LT.20000.0) THEN
         T = 216.65
         P = 22690.0 * EXP(-.034164*(ALT-11000.0)/216.65)
         GOTO 100
      ENDIF

      IF (ALT.GE.20000.0 .AND. ALT.LT.32000.0) THEN
         T = 216.65 + .001 * (ALT - 20000.0)
         P = 5528.0 * (216.65/T)**(.034164/.001)
         GOTO 100
      ENDIF

      IF (ALT.GE.32000.0 .AND. ALT.LT.47000.0) THEN
         T = 228.65 + .0028*(ALT-32000.0)
         P = 888.8 * (228.65/T)**(.034164/.0028)
         GOTO 100
      ENDIF

      IF (ALT.GE.47000.0 .AND. ALT.LT.52000.0) THEN
         T = 270.65
```

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```fortran
          P = 115.8 * EXP(-.034164 * (ALT - 47000.0)/T)
          GOTO 100
      ENDIF

      IF (ALT.GE.52000.0 .AND. ALT.LT.61000.0) THEN
          T = 270.65 - .002*(ALT - 52000.0)
          P = 62.21 * (270.65/T)**(-.034164/.002)
      ENDIF

100   AIRRHO = .003484 * P / T
      AIRVIS = 1.458E-06 * (T**1.5) / (T + 110.4)

      END
```

```fortran
C  *****************************************************************
C                      SUBROUTINE VFALL
C
C     THIS SUBROUTINE CALCULATES THE FALL VELOCITY OF A FALLOUT PARTICLE
C  AT A GIVEN ALTITUDE USING DAVIES-MACDONALD FALL MECHANICS.
C  *****************************************************************
C                      VARIABLE DEFINITIONS
C
C  1.  RYNOLD - THE REYNOLDS NUMBER.
C  2.  R2CD   - THE SQUARE OF THE REYNOLDS NUMBER MULTIPLIED BY THE
C               COEFFICIENT OF DRAG OF THE PARTICLE.
C  3.  RMET   - RADIUS OF THE PARTICLE IN METERS.
C  4.  CF     - EMPIRICAL CORRECTION FACTOR FOR THE VELOCITY OF A
C               SPHERICAL PARTICLE AT HIGH ALTITUDES.  TAKEN FROM DELFIC.
C  5.  VZ     - FALL VELOCITY OF THE PARTICLE IN M/S.
C  *****************************************************************

      SUBROUTINE VFALL(AIRRHO,RHOF,RADIUS,AIRVIS,VZ)

      REAL AIRRHO, RHOF, AIRVIS, RYNOLD, R2CD, RMET, G, LIOREY, RADIUS,
     1     LGR2CD

      G = 9.81

      RMET = RADIUS / 1.0E+06

C  USE MCDONALD-DAVIES FALL MECHANICS TO DETERMINE THE PARTICLE FALL
C  FALL VELOCITY.
      R2CD = 32.0 * AIRRHO * RHOF * G * (RMET**3.0) / (3.0*AIRVIS**2.0)

      IF (R2CD.LE.100.0) THEN
          RYNOLD = R2CD/24.0 - 2.3363E-04*(R2CD**2.0)
     1             + 2.0154E-06*(R2CD**3.0) - 6.9105E-09*(R2CD**4.0)
      ELSE
          LGR2CD = LOG10(R2CD)
          LIOREY = -1.29536 + .986*LGR2CD - 0.046677*(LGR2CD**2.0)
     1             + .0011235*(LGR2CD**3.0)
          RYNOLD = 10.00**LIOREY
      ENDIF

      CF = 1.0 + 1.165E-07/(RMET*AIRRHO)
      VZ = RYNOLD * AIRVIS * CF / (2.0 * AIRRHO * RMET)

      END
```

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```
C  ********************************************************************
C
C                          SUBROUTINE EPSLON
C
C       THIS SUBROUTINE CALCULATES THE EPSILON COEFFICIENTS FOR COMPUTING
C  THE ASSOCIATED LEGENDRE POLYNOMIALS WITH THE RECURSION RELATION IN
C  NWS 30 P24.  THE CODE IN THIS SUBROUTINE IS A DUPLICATE OF THE CODE
C  FOUND IN HOPKIN'S MODEL.
C  ********************************************************************
C
C                          VARIABLE DEFINITIONS
C
C  1.  JCAP   - TRUNCATION LIMIT.
C  2.  EPS    - EPSILON COEFFICIENTS.
C  3.  L      - LATITUDINAL INDEX.
C  4.  N      - LONGITUDINAL INDEX.
C  ********************************************************************

      SUBROUTINE EPSLON(JCAP,EPS)

      DOUBLE PRECISION EPS(1), A

      JCAP1 = JCAP + 1
      JCAP2 = JCAP + 1

      DO 100 LL = 1,JCAP1
          L = LL - 1
          JLE = L * JCAP2

          DO 110 INDE = 2,JCAP2
              N = L + INDE -1
              A = (N*N - L*L) / (4.D+0 * N*N - 1.D+0)
              EPS(JLE+INDE) = DSQRT(A)
110       CONTINUE
100   CONTINUE

      DO 200 LL = 1,JCAP1
          JLE = (LL-1) * JCAP2
          EPS(JLE+1) = 0.D+0
200   CONTINUE

      END
```

```
C ************************************************************
C
C                     SUBROUTINE UVCOMP
C
C     THIS SUBROUTINE CALCULATES THE WIND VECTOR COMPONENTS FROM NWS
C SPECTRAL COEFFICIENTS.  IT DUPLICATES A SUBROUTINE IN HOPKIN'S
C CODE.
C     THERE ARE JCAP+1 LATITUDINAL INDICES AND JCAP+1 LONGITUDINAL INDICES
C IN THE SPHERICAL HARMONICS SUMMATION.
C ************************************************************
C
C                     VARIABLE DEFINITIONS            -
C
C  1.  CU    - COMPLEX SPECTRAL COEFFICIENTS FOR THE X (W-E) WIND
C                COMPONENTS.
C  2.  CV    - COMPLEX SPECTRAL COEFFICIENTS FOR THE Y (S-N) WIND
C                COMPONENTS.
C  3.  EIL   - QUANTITY EQUAL TO EXP(IL*LAMBDA), WHERE I IS THE
C                IMAGINARY NUMBER, L IS THE LATITUDINAL INDEX, AND
C                LAMBDA IS THE LONGITUDE IN RADIANS.
C  4.  US    - THE X OR LONGITUDINAL COMPONENT OF THE WIND VELOCITY AT A
C                GIVEN POSITION IN M/SEC.
C  5.  VS    - THE Y OR LATITUDINAL COMPONENT OF THE WIND VELOCITY AT A
C                GIVEN POSITION IN M/SEC.
C  6.  LL    - LATITUDINAL INDEX.
C  7.  NN    - LONGITUDINAL INDEX.
C  8.  USUM  - PSEUDO WIND COMPONENT IN THE LONGITUDINAL DIRECTION.  THE
C                REAL PART OF THE SPECTRAL EXPANSION.
C  9.  VSUM  - PSEUDO WIND COMPONENT IN THE LATITUDINAL DIRECTION.  THE
C                REAL PART OF THE SPECTRAL EXPANSION.
C ************************************************************

      SUBROUTINE UVCOMP(CC,RR,LVL,EPS,CU,CV,US,VS)

      PARAMETER (JCAP=30)

      COMPLEX CU(12,JCAP+1,JCAP+1), CV(12,JCAP+1,JCAP+1),
     1        EIL, USUM, VSUM

      DOUBLE PRECISION EPS(JCAP+1,JCAP+1), CC, RR

      REAL PLN(JCAP+1,JCAP+1)

      PI = 3.141593

      JCAP1 = JCAP + 1
      JCAP2 = JCAP + 1

      CALL PLN3(PLN,CC,JCAP,EPS)

      USUM = 0.0
      VSUM = 0.0

      DO 10 LL = 1,JCAP1
```

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```fortran
            L = LL - 1
            EIL = CMPLX(DCOS(L*RR),DSIN(L*RR))

            DO 12 NN = 1,JCAP2
                AA = 2.0
                IF (L.EQ.0) AA = 1.0
                USUM = USUM + AA * PLN(NN,LL) * CU(LVL,NN,LL) * EIL
                VSUM = VSUM + AA * PLN(NN,LL) * CV(LVL,NN,LL) * EIL
12          CONTINUE
10      CONTINUE

        IF (ABS(CC).LT.1.D-10) THEN
            PRINT*,'   **** NORTH POLE ****'
            GOTO 9999
        ENDIF

C CALCULATE THE WIND VECTOR COMPONENTS.
        US = REAL(USUM) / DSIN(CC)
        VS = REAL(VSUM) / DSIN(CC)

9999  END
```

122

```
C ******************************************************************
C
C                            SUBROUTINE PLN3
C
C       THIS SUBROUTINE CALCULATES THE ASSOCIATED LEGENDRE POLYNOMIALS
C    FOR THE WIND COMPONENTS USING THE RECURSION RELATIONS IN BELOUSOV AND
C    NWS 30 P24.  IT IS A DUPLICATE OF A SUBROUTINE FOUND IN HOPKIN'S CODE.
C ******************************************************************
C
C                            VARIABLE DEFINITIONS
C
C   1.  PLN      - ASSOCIATED LEGENDRE POLYNOMIAL.  THE RECURSION RELATION
C                  USED TO CALCULATE IT IS:
C                       PLN(L,N+1) = (X*PLN(L,N) - EPS(L,N)*PLN(L,N-1))
C                                    / EPS(L,N+1)
C                  WHERE L IS THE LATITUDINAL INDEX,
C                        N IS THE LONGITUDINAL INDEX,
C                        PLN IS A FUNCTION OF X,
C                        X = COS(LATITUDE IN RADIANS).
C   2.  L        - LATITUDINAL INDEX.
C   3.  N        - LONGITUDINAL INDEX.
C ******************************************************************

      SUBROUTINE PLN3(PLN,CC,JCAP,EPS)

      DOUBLE PRECISION CC, EPS(1), SINLAT, COS2, PROD, A, B, FL,
     1                 P1, P2, P3, UNFLOW

      REAL PLN(1)

      DATA UNFLOW/0.75D-73/

      SINLAT = DCOS(CC)
      COS2 = 1.D+0 - SINLAT*SINLAT
      PROD = 1.D+0
      A = 1.D+0
      B = 0.D+0
      JCAP1 = JCAP + 1
      JCAP2 = JCAP + 1

      DO 300 LL = 1,JCAP1
          L = LL - 1
          FL = L
          JLE = L * JCAP2
          IF (L.EQ.0) GOTO 400
          A = A + 2.D+0
          B = B + 2.D+0

C FIX ANY UNDERFLOW VALUES.
          IF (PROD.LE.UNFLOW) PROD = 0.D+0
          PROD = PROD * COS2 * A / B
400       CONTINUE

          P1 = DSQRT(0.5D+0 * PROD)
```

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```fortran
          PLN(JLE+1) = SNGL(P1)
          P2 = DSQRT(2.D+0 - FL + 3.D+0) * SINLAT * P1
          PLN(JLE+2) = SNGL(P2)

          DO 500 N = 3,JCAP2
             LINDEX = JLE + N
             P3 = (SINLAT*P2 - EPS(LINDEX-1)*P1) / EPS(LINDEX)
             PLN(LINDEX) = SNGL(P3)
             P1 = P2
             P2 = P3
500       CONTINUE
300    CONTINUE

       END
```

```
C ****************************************************************
C
C                          SUBROUTINE LAYERS
C
C     THIS SUBROUTINE LOCATES THOSE ATMOSPHERIC LAYER BOUNDARIES
C  WHICH BRACKET THE INJECTION HEIGHT OF THE PARTICLE.
C ****************************************************************

      SUBROUTINE LAYERS(LCH,SPCLEV,LVL,HU,HL)

      REAL LCH, SPCLEV(0:30), HU, HL

      INTEGER LVL
      IF (LCH.GT.SPCLEV(0) .AND. LCH.LE.SPCLEV(1)) THEN
           LVL = 1
           HU = SPCLEV(1)
           HL = SPCLEV(0)
           GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(1) .AND. LCH.LE.SPCLEV(2)) THEN
           LVL = 2
           HU = SPCLEV(2)
           HL = SPCLEV(1)
           GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(2) .AND. LCH.LE.SPCLEV(3)) THEN
           LVL = 3
           HU = SPCLEV(3)
           HL = SPCLEV(2)
           GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(3) .AND. LCH.LE.SPCLEV(4)) THEN
           LVL = 4
           HU = SPCLEV(4)
           HL = SPCLEV(3)
           GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(4) .AND. LCH.LE.SPCLEV(5)) THEN
           LVL = 5
           HU = SPCLEV(5)
           HL = SPCLEV(4)
           GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(5) .AND. LCH.LE.SPCLEV(6)) THEN
           LVL = 6
           HU = SPCLEV(6)
           HL = SPCLEV(5)
           GOTO 200
      ENDIF
```

```fortran
      IF (LCH.GT.SPCLEV(6) .AND. LCH.LE.SPCLEV(7)) THEN
          LVL = 7
          HU = SPCLEV(7)
          HL = SPCLEV(6)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(7) .AND. LCH.LE.SPCLEV(8)) THEN
          LVL = 8
          HU = SPCLEV(8)
          HL = SPCLEV(7)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(8) .AND. LCH.LE.SPCLEV(9)) THEN
          LVL = 9
          HU = SPCLEV(9)
          HL = SPCLEV(8)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(9) .AND. LCH.LE.SPCLEV(10)) THEN
          LVL = 10
          HU = SPCLEV(10)
          HL = SPCLEV(9)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(10) .AND. LCH.LE.SPCLEV(11)) THEN
          LVL = 11
          HU = SPCLEV(11)
          HL = SPCLEV(10)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(11) .AND. LCH.LE.SPCLEV(12)) THEN
          LVL = 12
          HU = SPCLEV(12)
          HL = SPCLEV(11)
          GOTO 200
      ENDIF

      IF (LCH.GT.SPCLEV(12)) THEN
          LVL = 13
          HU = SPCLEV(12)
          HL = SPCLEV(12)
      ENDIF

200   END
```

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```
C  **********************************************************************
C
C                    SUBROUTINE ACTVTY
C
C       THIS SUBROUTINE CALCULATES THE ACTIVITY ON THE GROUND GIVEN THE
C  HOTLINE DATA.  IT USES A SMEAR EQUATION WITH A GENERALIZED F(X,Y)
C  DISTRIBUTION TO CALCULATE THE DOSE RATE AND DOSE.
C  **********************************************************************
C                    VARIABLE DEFINITIONS
C
C   1.  NORCON  - SOURCE NORMALIZATION CONSTANT FROM DELFIC.  UNITS OF
C                 ROENTGEN-KM2/HR-KILOTON.
C   2.  ALPH0   - LN OF THE MEDIAN PARTICLE RADIUS.
C   3.  ALPH2   - LN OF THE MEDIAN PARTICLE SURFACE AREA.
C   4.  ALPH3   - LN OF THE MEDIAN PARTICLE VOLUME.
C   5.  AR      - ACTIVITY-SIZE DISTRIBUTION IN INVERSE MICRONS.
C   6.  BETA    - LOGARITHMIC SLOPE OF THE NUMBER-SIZE DISTRIBUTION.
C   7.  CXHOT   - X POSITION IN KILOMETERS FOR A USER SPECIFIED DOSE
C                 RATE CONTOUR VALUE ON THE HOTLINE.
C   8.  CXHOT1  - BEGINNING AND END X LOCATION IN KILOMETERS FOR A GIVEN
C                 DOSE RATE CONTOUR.
C   9.  CYHOT   - SAME AS CXHOT BUT FOR Y POSITION.
C  10.  CYHOT1  - SAME AS CXHOT1 BUT FOR THE Y DIRECTION.
C  11.  DOSE    - DOSE AT GX, GY IN ROENTGENS.
C  12.  DRATE   - DOSE RATE CONTOUR VALUE IN R/HR SPECIFIED BY USER.
C  13.  DRATEO  - DOSE RATE ON THE HOTLINE IN R/HR AT A PARTICLE IMPACT
C                 POINT.
C  14.  DRDT    - RATE OF CHANGE IN SIZE OF PARTICLES HITTING THE GROUND
C                 IN MICRONS/HOUR.
C  15.  DRMAX   - MAXIMUM DOSE RATE VALUE ON THE HOTLINE FOR ALL PARTICLE
C                 SIZES.
C  16.  DSRTL   - CALCULATED DOSE RATE VALUE IN R/HR AT GXL,GYL.  SHOULD BE
C                 CLOSE TO DESIRED "DRATE" VALUE.
C  17.  DSRTR   - CALCULATED DOSE RATE VALUE IN R/HR AT GXR,GYR.  SHOULD BE
C                 CLOSE TO DESIRED "DRATE" VALUE.
C  18.  GTA     - FRACTIONAL RATE OF ACTIVITY ARRIVING ON THE GROUND AT
C                 TIME T IN INVERSE HOURS.
C  19.  GXL     - X POSITION OF A POINT OFF THE HOTLINE IN KILOMETERS, ON
C                 THE LEFT SIDE OF THE HOTLINE AS YOU WALK ALONG THE
C                 HOTLINE FROM GROUND ZERO.
C  20.  GXR     - SAME AS GXL EXCEPT THE POINT IS LOCATED ON THE RIGHT
C                 SIDE OF THE HOTLINE.
C  21.  GYL     - SAME AS GXL EXCEPT FOR THE Y COORDINATE.
C  22.  GYR     - SAME AS GXR EXCEPT FOR THE Y COORDINATE.
C  23.  REARTH  - RADIUS OF THE EARTH IN METERS.
C  24.  SHEARX  - COMPONENT OF SIGX DUE TO WIND SHEAR.  UNITS OF SQUARE
C                 KILOMETERS.
C  25.  SHEARY  - COMPONENT OF SIGY DUE TO WIND SHEAR.  UNITS OF SQUARE
C                 KILOMETERS.
C  26.  SIGX    - STANDARD DEVIATION IN THE X DIRECTION OF THE CLOUD
C                 ACTIVITY DISTRIBUTION.  UNITS OF KILOMETERS.
C  27.  SIGY    - SAME AS SIGX BUT IN THE Y DIRECTION.
C  28.  SIGZ    - STANDARD DEVIATION OF THE VERTICAL DISTRIBUTION IN THE
C                 CLOUD IN KILOMETERS.
```

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C  29.  SIGO   - STANDARD DEVIATION OF THE INITIAL HORIZONTAL CLOUD
C                 DISTRIBUTION IN KILOMETERS.
C  30.  SLP    - SLOPE OF THE STRAIGHT LINE EXTENDING FROM GROUND ZERO
C                 TO A PARTICLE IMPACT POINT ON THE HOTLINE.
C  31.  TASK   - TIME IN HOURS DURING WHICH TOROIDAL MOTION IS IMPORTANT
C                 IN SPREADING THE CLOUD.
C  32.  TOROID - COMPONENT OF SIGX AND SIGY DUE TO TOROIDAL MOTION OF
C                 CLOUD.  UNITS OF SQUARE KILOMETERS.
C  33.  XHOT   - X POSITION IN KILOMETERS ON THE HOTLINE FOR A GIVEN
C                 PARTICLE.
C  34.  YHOT   - SAME AS XHOT, EXCEPT IN Y DIRECTION.
C  *******************************************************************

       SUBROUTINE ACTVTY

       REAL YLD, FV, A, B, C, BETA1,
      1      NORCON, SIGX, SIGY, PI, LOGRAD, MFACT, ALPHO, RADLON(100),
      1      BETA, ALPH2, ALPH3, DRATE(100), XO, YO, COLRAD(100),
      1      FF, TEXIT, LNYM, HC, TC, SIGO, SIGZ, GTA, AR, REARTH,
      1      DRATEO(100), GXR(100), GYR(100), DLONO, DLATO, QUAN1,
      1      RADMIC(100), XHOT(100), YHOT(100), VXHOT(100), VYHOT(100),
      1      DSRTR(100), DSRTL(100), SHRX(100), SHRY(100), DRDT(100),
      1      INJHGT(100), TARRIV(100), Q1(100), Q2(100),
      1      Q3(100), LOC, CXHOT, CYHOT, GXL(100), GYL(100)

       INTEGER CNUM, NP, M

C  FILE DIAGNOS CONTAINS DIAGNOSTIC DATA FOR EACH PARTICLE SIZE, AND IS
C  NOT USED AS INPUT TO ANY OTHER PROGRAM.
       OPEN (9,FILE='DIAGNOS',ERR=100)
       WRITE (9,673) YLD, DLONO, DLATO
673    FORMAT ('YIELD (KT) = ',F10.3,5X,'DLONO = ',F8.3,5X,
      1          'DLATO = ',F8.3,/)

       OPEN (6,FILE='DOSERTE',ERR=100)

       OPEN (5,FILE='HOTLINE',ERR=100)
       REWIND 5
       READ (5,'(14F10.3)') YLD, FV, RMED, BETA1, RHOF,

      1      DLONO, DLATO, RRO, CCO, XO, YO, TEXIT, FF, NORCON
       WRITE (6,'(14F10.3)') YLD, FV, RMED, BETA1, RHOF,
      1      DLONO, DLATO, RRO, CCO, XO, YO, TEXIT, FF, NORCON
       DO 10 I = 1,100
          READ (5,'(10E12.6)',END=20) RADMIC(I), XHOT(I), YHOT(I),
      1          COLRAD(I), RADLON(I), SHRX(I),
      1          SHRY(I), DRDT(I), INJHGT(I), TARRIV(I)

10     CONTINUE
20     NP = I - 1
       CLOSE (5)

C  READ IN THE USER-SPECIFIED CONTOUR DOSE RATES.
       OPEN (5,FILE='CONTOUR',ERR=100)
```

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```fortran
      REWIND 5
      DO 30 I = 1,100
          READ (5,'(E10.3)',END=40) DRATE(I)
30    CONTINUE
40    CNUM = I - 1

      PI = 3.141593
      REARTH = 6356766.0
      ALPHO = LOG(RMED)
      BETA = LOG(BETA1)
      ALPH2 = ALPHO + 2.0 * BETA**2.0
      ALPH3 = ALPHO + 3.0 * BETA**2.0
      LNYM = LOG(YLD/1000.0)
      SIGO = 1.609 * EXP(0.7 + LNYM/3.0
     1              - 3.25/(4.0 + (LNYM + 5.4)**2.0))

      FINITY = -1.0E+25
      ZERO = 0.0
      WRITE (6,'(5E12.5)') ZERO, ZERO, ZERO, ZERO, ZERO


C  CALCULATE THE DOSE RATE ON THE HOTLINE AT THE PARTICLE ARRIVAL POINTS.
      DRMAX = 0.0
      DO 50 I = NP,1,-1
          MFACT = 1.0 / (SQRT(2.0*PI) * BETA * RADMIC(I))
          LOGRAD = LOG(RADMIC(I))

          AR = FV * MFACT * EXP(-0.5 * ((LOGRAD-ALPH3)/BETA)**2.0) +
     1          (1-FV) * MFACT * EXP(-0.5 * ((LOGRAD-ALPH2)/BETA)**2.0)

          GTA = AR * DRDT(1)
          WRITE (9,666) RADMIC(I), GTA, DRDT(I)
666       FORMAT ('RADMIC = ',F10.3,5X,'GTA = ',E12.5,5X,
     1              'DRDT = ',E12.5)

C         CALCULATE SIGY AND SIGX FOR THE WINDS.
          SIGZ = 0.18 * INJHGT(I)
          IF (TARRIV(I).LT.3.0) THEN
              TASK = TARRIV(I)
          ELSE
              TASK = 3.0
          ENDIF
          HC = (5.28/1.609) * INJHGT(I)
          TC = 0.2 * HC - 2.5 * (HC/60.0)**2.0
          SIGY = SQRT(SIGO**2.0 * (1 + 8.0*TASK/TC)
     1              + (SIGZ*SHRY(I)*TARRIV(I)/2.0)**2.0)
          SIGX = SQRT(SIGO**2.0 * (1 + 8.0*TASK/TC)
     1              + (SIGZ*SHRX(I)*TARRIV(I)/2.0)**2.0)

          TOROID = SIGO**2.0 * (1.0 + 8.0*TASK/TC)
          SHEARX = (SIGZ*SHRX(I)*TARRIV(I)/2.0)**2.0
          SHEARY = (SIGZ*SHRY(I)*TARRIV(I)/2.0)**2.0
```

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```
              Q1(I) = NORCON * YLD * FF * GTA / SQRT(2.0*PI)
              Q2(I) = 1.0 / SQRT((SIGY * XHOT(I) / TARRIV(I))**2.0
     1              + (SIGX * YHOT(I) / TARRIV(I))**2.0)
              Q3(I) = -0.5 / ((SIGY*XHOT(I))**2.0 + (SIGX*YHOT(I))**2.0)

              DRATEO(I) = Q1(I) * Q2(I)

C        WRITE OUT MORE DIAGNOSTIC DATA.
         WRITE (9,667) SIGZ,SIGO,TC
667      FORMAT (5X,'SIGZ = ',F10.3,5X,'SIGO = ',F10.3,5X,
     1              'TC = ',F10.3)
         WRITE (9,670) SHRX(I),SHRY(I),TARRIV(I)
670      FORMAT (5X,'SHRX = ',E12.5,5X,'SHRY = ',E12.5,5X,
     1              'TARRIV = ',E12.5)
         WRITE (9,669) TOROID,SHEARX,SHEARY
669      FORMAT (5X,'TOROID = ',E12.5,5X,'SHEARX = ',E12.5,5X,
     1              'SHEARY = ',E12.5)
         WRITE (9,672) INJHGT(I)
672      FORMAT (5X,'PARTICLE INJECTION HEIGHT = ',F10.3)
         WRITE (9,668) Q1(I),Q2(I),Q3(I)
668      FORMAT (5X,'Q1 = ',E12.5,5X,'Q2 = ',E12.5,5X,
     1              'Q3 = ',E12.5)
         WRITE (9,671) SIGX,SIGY,DRATEO(I)
671      FORMAT (5X,'SIGX = ',E12.5,5X,'SIGY = ',E12.5,5X,
     1              'DRATE = ',E12.5,/)

         IF (DRATEO(I).GT.DRMAX) THEN
             DRMAX = DRATEO(I)
         ENDIF

         WRITE (6,'(5E12.5)') XHOT(I), YHOT(I), DRATEO(I), DRATEO(I),
     1                        RADMIC(I)
50       CONTINUE

C  THIS LINE SERVES AS A MARKER TO THE PLOTTING PROGRAM TO INDICATE
C  BREAKS BETWEEN HOTLINE POINTS AND CONTOUR POINTS, AND ALSO BETWEEN
C  DIFFERENT SETS OF CONTOUR POINTS.
       WRITE (6,'(5E12.5)') FINITY, FINITY, FINITY, FINITY, FINITY


C  FIND THE LOCATIONS OFF THE HOTLINE WHERE THE DOSE RATE IS EQUAL TO
C  THE USER SPECIFIED DOSE RATES.
       DO 60 I = 1,CNUM

         IF (DRATE(I).GE.DRMAX) GOTO 60

C        THE POINT CXHOT1,CYHOT1 IS THE STARTING POINT FOR A GIVEN DOSE
C        RATE CONTOUR.  THIS POINT IS FOUND BY LINEARLY INTERPOLATING
C        BETWEEN GROUND ZERO AND THE HOTLINE VALUE CLOSEST TO GROUND
C        ZERO.  THE DOSE RATE AT GROUND ZERO IS TAKEN TO BE ZERO.

         CXHOT1 = (DRATE(I)/DRATEO(NP)) * XHOT(NP)
         CYHOT1 = (DRATE(I)/DRATEO(NP)) * YHOT(NP)
```

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```
              WRITE (6,'(5E12.5)') CXHOT1, CYHOT1, DRATE(T),
     1                             DRATE(1), ZERO

C        FIND THE DOSE RATE ALONG THE GAUSSIANS EXTENDING FROM THE
C        ARRIVAL POINTS ALONG THE HOTLINE.
         DO 70 K = NP,1,-1

            IF (DRATEO(K).LE.DRATE(I)) GOTO 70

            QUAN1 = LOG(DRATE(I) / (Q1(K)*Q2(K))) / Q3(K)

            IF (XHOT(K).NE.0.0) SLP = YHOT(K) / XHOT(K)

            IF (YHOT(K).LT.0.0 .AND. XHOT(K).EQ.0.0) SLP = -1.0E+30

            IF (YHOT(K).GT.0.0 .AND. XHOT(K).EQ.0.0) SLP = 1.0E+30

            IF (YHOT(K).NE.0.0) THEN
               A = YHOT(K)*YHOT(K) + 2.0*XHOT(K)*XHOT(K)
     1                + XHOT(K)**4.0/YHOT(K)**2.0
               B = -(2.0*XHOT(K)*YHOT(K)*YHOT(K) + 4.0*XHOT(K)**3.0
     1                + 2.0*XHOT(K)**5.0/YHOT(K)**2.0)
               C = 2.0*XHOT(K)**4.0 + XHOT(K)**2.0 * YHOT(K)**2.0
     1                + XHOT(K)**6.0 / YHOT(K)**2.0 - QUAN1
            ENDIF

            IF (SLP.LT.0.0) THEN
               IF (YHOT(K).GT.0.0) THEN
                  GXR(K) = (-B + SQRT(B*B - 4.0*A*C)) / (2.0*A)
                  GXL(K) = (-B - SQRT(B*B - 4.0*A*C)) / (2.0*A)
               ELSE
                  GXR(K) = (-B - SQRT(B*B - 4.0*A*C)) / (2.0*A)
                  GXL(K) = (-B + SQRT(B*B - 4.0*A*C)) / (2.0*A)
               ENDIF
            ENDIF

            IF (SLP.GT.0.0) THEN
               IF (YHOT(K).GT.0.0) THEN
                  GXR(K) = (-B + SQRT(B*B - 4.0*A*C)) / (2.0*A)
                  GXL(K) = (-B - SQRT(B*B - 4.0*A*C)) / (2.0*A)
               ELSE
                  GXR(K) = (-B - SQRT(B*B - 4.0*A*C)) / (2.0*A)
                  GXL(K) = (-B + SQRT(B*B - 4.0*A*C)) / (2.0*A)
               ENDIF
            ENDIF

            IF (SLP.EQ.0.0) THEN
               GXR(K) = XHOT(K)
               GXL(K) = XHOT(K)
            ENDIF

            IF (SLP.NE.0.0) THEN
               GYR(K) = (-XHOT(K)/YHOT(K)) * GXR(K)
     1                   + YHOT(K) + XHOT(K)*XHOT(K)/YHOT(K)
```

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```fortran
                    GYL(K) = (-XHOT(K)/YHOT(K)) * GXL(K)
     1                        + YHOT(K) + XHOT(K)*XHOT(K)/YHOT(K)
                ELSE
                    GYR(K) = -SQRT(QUAN1) / XHOT(K)
                    GYL(K) = SQRT(QUAN1) / XHOT(K)
                ENDIF

                DSRTR(K) = Q1(K) * Q2(K) * EXP( Q3(K)
     1                    * (GXR(K)*YHOT(K) - GYR(K)*XHOT(K))**2.0 )
                DSRTL(K) = Q1(K) * Q2(K) * EXP( Q3(K)
     1                    * (GXL(K)*YHOT(K) - GYL(K)*XHOT(K))**2.0 )
C               WRITE OUT THE DOSE RATES THAT ARE ON THE RIGHT SIDE OF
C               OF THE HOTLINE AS YOU WALK FROM GROUND ZERO ALONG THE
C               HOTLINE.
                WRITE (6,'(5E12.5)') GXR(K), GYR(K), DRATE(I),
     1                               DSRTR(K), RADMIC(K)

70          CONTINUE


C           LOCATE THE POINT ALONG THE HOTLINE WHERE THE DOSE RATE IS THE
C           USER-SPECIFIED CONTOUR DOSE RATE.  THIS IS SIMPLY A LINEAR
C           INTERPOLATION BETWEEN TWO HOTLINE DOSE RATE VALUES.
            DO 80 M = 2,NP
                IF (DRATE(I).GE.DRATEO(M-1)
     1                           .AND. DRATE(I).LT.DRATEO(M)) GOTO 85
                GOTO 80
85              LOC = (DRATE(I) - DRATEO(M-1)) / (DRATEO(M) - DRATEO(M-1))
                CXHOT = LOC * (XHOT(M) - XHOT(M-1)) + XHOT(M-1)
                CYHOT = LOC * (YHOT(M) - YHOT(M-1)) + YHOT(M-1)
                WRITE (6,'(5E12.5)') CXHOT, CYHOT, DRATE(I),
     1                               DRATE(I), ZERO
                GOTO 75
80          CONTINUE

C           IF THE USER SPECIFIED DOSE RATE IS TOO SMALL TO BE ON THE HOTLINE,
C           PUT IN A MARKER TO INDICATE THE BREAK IN THE CONTOUR.
            WRITE (6,'(5E12.5)') FINITY, FINITY, FINITY, FINITY, FINITY


C           WRITE OUT THE DOSE RATES THAT ARE ON THE LEFT SIDE OF THE
C           HOTLINE AS YOU WALK FROM GROUND ZERO ALONG THE HOTLINE.
75          DO 77 K = 1,NP

                IF (DRATEO(K).LE.DRATE(I)) GOTO 77

                WRITE (6,'(5E12.5)') GXL(K), GYL(K), DRATE(I),
     1                               DSRTL(K), RADMIC(K)

77          CONTINUE
```

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```
C            END THE DOSE RATE CONTOUR AT THE POINT WHERE IT STARTED.


             WRITE (6,'(5E12.5)') CXHOT1, CYHOT1, DRATE(1),
      1                            DRATE(I), ZERO
             WRITE (6,'(5E12.5)') FINITY, FINITY, FINITY, FINITY, FINITY

60      CONTINUE

100     CLOSE (6)
        CLOSE (9)
        END
```

Appendix II

HYDMAP Source Code

This appendix contains the HYDMAP source code. HYDMAP is written in Fortran V and uses DISSPLA subroutines to draw the contours and maps. All physical variables and their units have been defined in the code.

134

```
C *****************************************************************
C                        PROGRAM HYDMAP
C
C     THIS PROGRAM TAKES THE "DOSERTE" FILE CREATED BY PROGRAM "HYDRA"
C AND PLOTS THE DATA OVER A USER SPECIFIED WORLD MAP.  "HYDRA" GIVES
C THE HOTLINE AND CONTOUR POINTS IN KILOMETERS.  THIS CODE TAKES THE
C DATA AND CONVERTS IT TO DEGREES.
C *****************************************************************
C     WRITTEN BY CAPT. TONY STRINES, JR. DURING THE PERIOD NOV-DEC 1986.
C *****************************************************************
C                        VARIABLE DEFINITIONS
C
C   1.   AREA   - THAT AREA OF THE WORLD YOU WISH TO MAP.
C   2.   BETA1  - LOG SLOPE OF THE ACTIVITY-SIZE DISTRIBUTION.
C   3.   CCO    - CO-LATITUDE OF GROUND ZERO IN RADIANS.
C   4.   COAST  - SPECIFIES WHAT COASTLINES DISSPLA IS TO DRAW.
C   5.   CX     - X COORDINATE IN KILOMETERS FOR A CONTOUR POINT.
C   6.   CY     - SAME AS CX, EXCEPT FOR THE Y COORDINATE.
C   7.   DEGKM  - CONVERSION FACTOR TO GO FROM KILOMETERS TO DEGREES.
C   8.   DLATO  - LATITUDE IN DEGREES OF GROUND ZERO.
C   9.   DLONO  - LONGITUDE IN DEGREES OF GROUND ZERO.
C  10.   DRATE  - USER SPECIFIED DOSE RATE CONTOUR IN R/HR.
C  11.   DX     - X COORDINATE IN DEGREES LONG. FOR A CONTOUR POINT.
C  12.   DXMAX  - MAXIMUM X COORDINATE IN DEGREES LONG. FOR ALL CONTOUR
C                   AND HOTLINE POINTS.
C  13.   DXORIG - MINIMUM X COORDINATE IN DEGREES LONG. FOR ALL CONTOUR
C                   AND HOTLINE POINTS.
C  14.   DXSTP  - PLACE A GRID LINE EVERY "DXSTP" DEGREES LONG.
C  15.   DY     - Y COORDINATE IN DEGREES LAT. FOR A CONTOUR POINT.
C  16.   DYMAX  - MAXIMUM Y COORDINATE IN DEGREES LAT. FOR ALL CONTOUR
C                   AND HOTLINE POINTS.
C  17.   DYORIG - MINIMUM Y COORDINATE IN DEGREES LAT. FOR ALL CONTOUR
C                   AND HOTLINE POINTS.
C  18.   DYSTP  - PLACE A GRID LINE EVERY "DYSTP" DEGREES LAT.
C  19.   FF     - FISSION FRACTION OF WEAPON, USUALLY .5.
C  20.   FV     - FRACTION OF ACTIVITY DISTRIBUTED IN PARTICLE VOLUME.
C  21.   NORCON - SOURCE NORMALIZATION CONSTANT IN R-KM2/HR-KILOTON.
C  22.   REARTH - RADIUS OF THE EARTH IN KILOMETERS.
C  23.   RHOF   - PARTICLE DENSITY IN KG/M3.
C  24.   RMED   - MEDIAN PARTICLE RADIUS OF THE ACTIVITY-SIZE DISTRIBUTION
C                   IN MICRONS.
C  25.   RRO    - LONGITUDINAL POSITION OF GROUND ZERO IN RADIANS.
C  26.   TEXIT  - AMOUNT OF TIME IN HOURS SPENT IN CONTAMINATED AREA.
C  27.   XMAX   - MAXIMUM X COORDINATE IN KILOMETERS FOR ALL CONTOUR AND
C                   HOTLINE POINTS.
C  28.   XORIG  - MINIMUM X COORDINATE IN KILOMETERS FOR ALL CONTOUR AND
C                   HOTLINE POINTS.
C  29.   XO     - X COORDINATE IN KILOMETERS OF GROUND ZERO.
C  30.   YLD    - YIELD OF THE WEAPON IN KILOTONS.
C  31.   YMAX   - MAXIMUM Y COORDINATE IN KILOMETERS FOR ALL CONTOUR AND
C                   HOTLINE POINTS.
C  32.   YORIG  - MINIMUM Y COORDINATE IN KILOMETERS FOR ALL CONTOUR AND
C                   HOTLINE POINTS.
C  33.   YO     - Y COORDINATE IN KILOMETERS OF GROUND ZERO.
```

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```
C  ******************************************************************

       PROGRAM HOTMAP

       REAL YLD, FV, RMED, BETA1, RHOF, DLONO, DLATO, RRO, CCO, XO, YO,
      1      TEXIT, FF, NORCON, XMAX, YMAX, DX(1000), DY(1000), XORIG,
      1      YORIG, CX(1000), CY(1000), DRATE(1000), PI, REARTH, DEGKM

       CHARACTER AREA*4,COAST*4

       DIMENSION LABEL(5), IPKRAY(500), LEGLAB(10)

       PI = 3.141593
       REARTH = 6356.766
       DEGKM = (.5 * PI * REARTH) / 90.0

       OPEN (9,FILE='CONERR',ERR=100)

       OPEN (5,FILE='DOSERTE',ERR=100)
       REWIND 5
       READ (5,'(14F10.3)') YLD, FV, RMED, BETA1, RHOF,
      1      DLONO, DLATO, RRO, CCO, XO, YO, TEXIT, FF, NORCON

       IF (DLONO.GT.180.) THEN
           DLONO = DLONO - 360.0
       ENDIF

       XMAX = 0.0
       YMAX = 0.0
       XORIG = 0.0
       YORIG = 0.0

C  LOCATE THE MAXIMUM X AND Y VALUES AND THE MINIMUM X AND Y VALUES
C  (XORIG, YORIG).
       DO 5 I = 1,1000
           READ (5,'(3E12.5)',END=10) CX(I), CY(I), DRATE(I)

           IF (CX(I).EQ.-1.0E+25) GOTO 5

           IF (CX(I).GT.XMAX) THEN
               XMAX = CX(I)
               XMAXY = CY(I)
           ENDIF

           IF (CX(I).LT.XORIG) THEN
               XORIG = CX(I)
               XORIGY = CY(I)
           ENDIF

           IF (CY(I).GT.YMAX) THEN
               YMAX = CY(I)
           ENDIF

           IF (CY(I).LT.YORIG) THEN
```

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```fortran
                YORIG = CY(1)
            ENDIF

5       CONTINUE
10      REWIND 5

        DXMAXY = DLATO + XMAXY / DEGKM
        DXMAX = DLONO + XMAX / (DEGKM*COS(DXMAXY*PI/180.))

        DXORY = DLATO + XORIGY / DEGKM
        DXORIG = DLONO + XORIG / (DEGKM*COS(DXORY*PI/180.))

        DYMAX = DLATO + YMAX / DEGKM
        DYORIG = DLATO + YORIG / DEGKM

        IF (DXMAX.GE.0.0) THEN
            DXMAX = NINT(ABS(DXMAX)/10. + .5) * 10.
            IF (DXMAX.GT.180.) THEN
                DXMAX = DXMAX - 360.
            ENDIF
        ELSE
            DXMAX = NINT(ABS(DXMAX)/10. - .5) * 10.
            DXMAX = -DXMAX
        ENDIF

        IF (DYMAX.GE.0.0) THEN
            DYMAX = NINT(ABS(DYMAX)/10. + .5) * 10.
            IF (DYMAX.GT.90.) THEN
                DYMAX = 180. - DYMAX
            ENDIF
        ELSE
            DYMAX = NINT(ABS(DYMAX)/10. - .5) * 10.
            DYMAX = -DYMAX
        ENDIF

        IF (DXORIG.GE.0.0) THEN
            DXORIG = NINT(ABS(DXORIG)/10. - .5) * 10.
        ELSE
            DXORIG = NINT(ABS(DXORIG)/10. + .5) * 10.
            DXORIG = -DXORIG
            IF (DXORIG.LT.-180.0) THEN
                DXORIG = 360.0 + DXORIG
            ENDIF
        ENDIF

        IF (DYORIG.GE.0.0) THEN
            DYORIG = NINT(ABS(DYORIG)/10. - .5) * 10.
        ELSE
            DYORIG = NINT(ABS(DYORIG)/10. + .5) * 10.
            DYORIG = -DYORIG
            IF (DYORIG.LT.-90.) THEN
                DYORIG = 180.0 + DYORIG
            ENDIF
        ENDIF
```

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```fortran
      DXSTP = ABS(DXMAX - DXORIG) / 5.
      DYSTP = ABS(DYMAX - DYORIG) / 5.

      PRINT *,'MAX X (DEG. LONGITUDE) = ',DXMAX
      PRINT *,'MIN X (DEG. LONGITUDE) = ',DXORIG
      PRINT *,'GRID LINES EVERY ',DXSTP,' DEG. LONGITUDE'
      PRINT *,' '
      PRINT *,'MAX Y (DEG. LATITUDE) = ',DYMAX
      PRINT *,'MIN Y (DEG. LATITUDE) = ',DYORIG
      PRINT *,'GRID LINES EVERY ',DYSTP,' DEG. LATITUDE'
      PRINT *,' '
      PRINT *,'IF THESE VALUES ARE ACCEPTABLE, ENTER 0 TO GO ON.'
      PRINT *,'IF YOU WANT TO PICK YOUR OWN VALUES, ENTER 1.'

      READ *, NOYES
      IF (NOYES.EQ.0) THEN
          GOTO 22
      ELSE
          PRINT *,'ENTER MAX X (DEG. LONG.):'
          READ *, DXMAX
          PRINT *,'ENTER MIN X (DEG. LONG.):'
          READ *, DXORIG
          PRINT *,'GRID LINE EVERY (DEG. LONG.):'
          READ *, DXSTP
          PRINT *,' '
          PRINT *,'ENTER MAX Y (DEG. LAT.):'
          READ *, DYMAX
          PRINT *,'ENTER MIN Y (DEG. LAT.):'
          READ *, DYORIG
          PRINT *,'GRID LINE EVERY (DEG. LAT.):'
          READ *, DYSTP
      ENDIF

22    CONTINUE

      PRINT *,'ENTER THE MAP YOU WISH TO USE:'
      PRINT *,'    "PAFR" FOR AFRICA,'
      PRINT *,'    "PASI" FOR ASIA,'
      PRINT *,'    "PAUS" FOR AUSTRALIA,'
      PRINT *,'    "PEUR" FOR EUROPE,'
      PRINT *,'    "PNOR" FOR NORTH AMERICA,'
      PRINT *,'    "POLI" FOR THE ENTIRE WORLD,'
      PRINT *,'    "PSOU" FOR SOUTH AMERICA,'
      PRINT *,' OR "USAM" FOR UNITED STATES BOUNDARIES.'
      PRINT *,' '
      PRINT *,'BE SURE TO PLACE SINGLE QUOTES AROUND THE FOUR LETTER'
      PRINT *,'MAP CODE, OR THE PROGRAM WILL NOT RUN.'
      PRINT *,' '

      READ *, AREA

      IF (AREA.EQ.'PAFR') COAST = 'AFRI'
      IF (AREA.EQ.'PASI') COAST = 'ASIA'
```

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```
      IF (AREA.EQ.'PAUS') COAST = 'AUST'
      IF (AREA.EQ.'PEUR') COAST = 'EURO'
      IF (AREA.EQ.'PNOR') COAST = 'NORT'
      IF (AREA.EQ.'POLI') COAST = 'COAS'
      IF (AREA.EQ.'PSOU') COAST = 'SOUT'

      WRITE (9,700) DXMAX, DXORIG, DXSTP
700   FORMAT ('DXMAX = ',F10.3,5X,'DXORIG = ',F10.3,5X,'DXSTP = ',F10.3)

      WRITE (9,701) DYMAX, DYORIG, DYSTP
701   FORMAT ('DYMAX = ',F10.3,5X,'DYORIG = ',F10.3,5X,'DYSTP = ',F10.3)

C  THE FOLLOWING CODE PRODUCES A CONTOUR PLOT FROM THE DATA FILE
C  DOSERTE USING DISSPLA SUBROUTINES.
      CALL COMPRS
      CALL PROJCT('MERCA')
      CALL YAXANG (0.)
      CALL XNAME (' ',1)
      CALL YNAME (' ',1)
      CALL AREA2D (6.,4.)

      CALL HEADIN ('DOSE RATE CONTOURS$',100,1.5,4)

      ENCODE (60,15,LABEL) YLD, FF
15    FORMAT ('YIELD (KT) = ',F9.3,'        FISSION FRACTION = ',F5.3,
     1         '$')
      CALL HEADIN (LABEL,100,1.,4)

      ENCODE (60,16,LABEL) RMED, BETA1
16    FORMAT ('RMED (MICRONS) = ',F7.3,'       BETA = ',F6.3,'$')
      CALL HEADIN (LABEL,100,1.,4)

      ENCODE (60,17,LABEL) DLONO, DLATO
17    FORMAT ('GROUND ZERO: LONG(DEG.) = ',F8.3,

     1             '        LAT(DEG.) = ',F7.3,'$')
      CALL HEADIN (LABEL,100,1.,4)

      CALL MAPGR(DXORIG,DXSTP,DXMAX,DYORIG,DYSTP,DYMAX)

C  CLEAR OUT ARRAY IPKRAY.
      NL = LINEST (IPKRAY,200,25)

C  READ THE DATA INTO THE PROPER ARRAYS AND CALL LEGEND-SETTING
C  ROUTINE.
      CALL HEIGHT (0.1)
      ILINES = 0
      DO 60 I=1,1000
          READ (5,'(3E12.5)',END = 65) CX(I), CY(I), DRATE(I)

          IF (CX(I).NE.-1.0E+25) GOTO 60

          ILINES = ILINES + 1
          IF (ILINES.NE.1) THEN
```

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```fortran
                        DSRATE = DRATE(L-1)
                        WRITE (9,555) DSRATE
555                     FORMAT ('DSRATE = ',F10.3)
                        ENCODE (25,20,LEGLAB) DSRATE
20                      FORMAT (F10.3,' ROENTGEN/HR$')
                        CALL LINES (LEGLAB,IPKRAY,ILINES)
                    ELSE
                        CALL LINES ('HOTLINE$',IPKRAY,ILINES)
                        WRITE (9,556)
556                     FORMAT ('HOTLINE')
                    ENDIF

60      CONTINUE
65      CONTINUE

        REWIND 5

C   GET THE WIDTH AND HEIGHT OF THE LEGEND AREA.
        XW = XLEGND (IPKRAY,ILINES)
        YW = YLEGND (IPKRAY,ILINES)

C   SET UP A BLANKED AREA FOR THE LEGEND.
        YL = 0.0 - YW - 1.0
        XL = (6.0 - XW) / 2.0

        CALL BLREC (XL,YL,XW + 0.2,YW + 0.2,0.02)
        CALL BLKEY (ID)

        IF (AREA.NE.'USAM') CALL MAPFIL(COAST)
        CALL MAPFIL(AREA)
        CALL THKFRM (.02)
        CALL FRAME
        CALL SCLPIC(0.5)

        WRITE (9,198) AREA
198     FORMAT ('AREA = ',A4)

        READ (5,'(F10.3)') YLD

        CALL RASPLN(0.)

C   READ THE DATA INTO THE PROPER ARRAYS AND CALL THE CURVE PLOTTING
C   ROUTINE.
        NPNTS = 0
        DO 30 I=1,1000
            READ (5,'(3E12.5)',END = 40) CX(I), CY(I), DRATE(I)

            IF (CX(I).EQ.-1.0E+25) GOTO 35

            NPNTS = NPNTS + 1
            DY(NPNTS) = DLATO + CY(I) / DEGKM
            DX(NPNTS) = DLONO + CX(I) / (DEGKM*COS(DY(NPNTS)*PI/180.))

            WRITE (9,702) DX(NPNTS), DY(NPNTS), NPNTS
```

```
702        FORMAT ('DX = ',E13.6,5X,'DY = ',E13.6,5X,'NPNTS = ',I3)
           GOTO 30

35         CALL CURVE (DX,DY,NPNTS,1)
           NPNTS = 0

30    CONTINUE

40    CALL RESET ('BLNK1')
      CALL RESET ('BLNK1')
      CALL DOT
      CALL GRID(1,1)
      CALL BLOFF(ID)
      CALL LEGEND (IPKRAY,ILINES,XL+.1,YL+.1)

      CALL ENDPL(0)
      CALL DONEPL

100   CLOSE (5)
      CLOSE (9)
      STOP
      END
```

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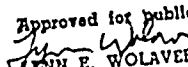
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19. ABSTRACT

A radioactive fallout code, HYDRA, has been developed that uses real winds to determine dose rate contours on the ground. These winds are calculated from spectral coefficients derived by the National Meteorological Center. HYDRA models the radioactive dust cloud as a set of pancake clouds, each cloud representing a different particle size group. Each particle size group is transported to the ground through a discretely layered atmosphere using McDonald-Davies fall mechanics. Dose rate contours are determined by smearing the cloud activity along the ground as the cloud descends.

HYDRA was evaluated against another variable wind fallout code named REDRAM. The two codes produced identical hotlines.

HYDRA is capable of overlaying dose rate contours on global maps through the use of DISSPLA software. A copy of the HYDRA source code is included in the report.